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FIRST LINES

OF

NATURAL PHILOSOPHY,

DIVESTED OF MATHEMATICAL FORMULÆ:

BEING A

PRACTICAL AND LUCID INTRODUCTION TO THE STUDY OF THE SCIENCE.

DESIGNED FOR

THE USE OF SCHOOLS AND ACADEMIES,

AND FOR READERS GENERALLY WHO HAVE NOT BEEN TRAINED TO THE STUDY OF THE EXACT SCIENCES, AND THOSE WHO WISH TO ENTER UNDERSTANDINGLY UPON THE STUDY OF THE MIXED SCIENCES.

BY REYNELL COATES, M. D.,

AUTHOR OF "PHYSIOLOGY FOR SCHOOLS."

ILLUSTRATED BY 264 CUTS.

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PREFACE.

This little work has been planned and executed under the conviction that whatever it is worth while to teach at all, it is worth while to teach thoroughly, and in a manner calculated to render the instruction practically useful to the student.

The author vaunts not the ability to manufacture young philosophers by wholesale, in a definite number of weeks or days; nor is he emulous of the ephemeral popularity which often results from writing an "easy book:" but he believes it no difficult task to teach young persons generally to reason philosophically, and to keep them interested in the subject of their studies while acquiring that mental training which should ever be considered the great end of common education. He believes that the best way to teach others is, to follow the route by which the teacher has acquired his own knowledge; because, by this means, his practical experience of the difficulties of the road becomes available, and he enables others to escape a host of obstacles with which he has become familiar. For this reason, the scissors have been thrown aside, precisely at the moment when they are taken up by most who set about writing a school-book.

The time and the labour of thought expended upon this volume would have been amply sufficient for the production of a whole series of "complete treatises" on all the physical sciences, executed according to the modern fash-

ionable process of school-book making, and it is much to be feared that the teacher himself will be obliged to read it through, before he will be entirely aware of all its contents, or perfectly informed as to the manner in which the subject matter is handled.

It is written in plain English—much of it Saxon—and is at least free from the absurdity which always attends upon philosophy when mounted upon stilts. But, as it is always better to allow our children to "make their own way in the world," after having duly attended to their moral and intellectual training, the book may now be safely left to stand upon its merits before that public which is somewhat too experienced, withal, to place great confidence in high pretensions.

The references, which the pupil will find essential to the proper understanding of the subject, are made to the numbers of the paragraphs, and not to those of the pages; and the questions at the end of the work, refer each to the appropriate portions of the text. The intelligent teacher will amplify, of course, upon the queries, which, however, are purposely designed to compel intelligent answers, and to preclude entirely the parrot-like system of instruction. Familiar illustrations, scarcely numerable, may be found, and applied to almost every demonstration, and ample room is thus allowed for the exercise of the talent both of pupil and preceptor.

The marked approval of the plan of instruction followed in the Physiology for Schools, from the same pen, leads to the belief that the application of this method to Natural Philosophy will not be less successful.

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NATURAL PHILOSOPHY.

CHAPTER I.

PROPERTIES OF MATTER.

INTRODUCTORY REMARKS.

1. The young infant is placed in the midst of a creation offering thousands of objects of attention, all of which are capable of making an impression upon one or more of the five senses; and it is only through the operation of the senses that we can obtain any idea of these objects.

2. When the child sees a brilliant object in the distance, instinct immediately prompts him to stretch out his hands to touch it. When first shown the moon on a clear night, he endeavours to seize it, and often weeps bitterly at his disappointment. But even this ineffectual effort is not without its usefulness. Finding that there is plenty of room on every side to allow of the free *extension* of its arms, the child acquires an idea of *space*. The abstract idea of *space* is so extremely simple, that the term neither requires nor admits of definition.

3. The moment that a child is permitted to crawl through space until it is able to reach and freely examine any *thing* which attracts its attention, it becomes a natural philosopher. By examining a variety of objects in succession, it soon discovers that they *all* possess certain characters in common, and that some of them present certain other characters peculiar to themselves. Characters of the former class have been termed *the general qualities or properties of things*, while those of the latter class are called *special or peculiar qualities or properties*.

4. Let us suppose an infant to wander from the cradle until it reaches some article of furniture,—a table, for instance. It then finds its further progress arrested by a solid barrier, through which it cannot penetrate, though it may crawl around this barrier without restraint. It immediately perceives that this barrier occupies a portion of space, and has a certain *extent*, which the infant is already able to

measure. It very soon learns, also, that where the table is, *nothing else can be at the same time*—and naturally concludes that there does exist *something* that possesses the property of *exclusively occupying space*. The infant soon encounters other articles, such as the fender, the bureau, the walls of the apartment, &c., all of which oppose its progress in the same manner, though they differ very widely in appearance, nature, and extent. The conclusion is irresistible. There are *many things* which possess the property of exclusively occupying space. Here, then, is a general property, common to a multitude of things so different in other qualities that our little philosopher soon feels the want of a word or term which shall include all things possessing this property. The English word used for this purpose is *matter;* which, as defined by natural philosophers, is—*that which exclusively occupies space:* and the property itself is called *impenetrability*.

5. Besides *extension*—which, as applied to matter, consists simply in the occupation of space—and *impenetrability*—by which is meant the exclusiveness of that occupancy—*matter* has several other general properties, that will be explained hereafter.

6. In speaking of the variety of objects which attract the attention of an infant, I have termed them "*things*." (3) But the word *thing*, has too many meanings to be safely used in teaching the first rudiments of natural philosophy. This term is really a modification of the word *think*, and signifies—*that which we can think of*. Now we can think of a multitude of *things* which have no material existence. Thus: *Knowledge is a good thing*,—but knowledge is not composed of matter. We must, therefore, find some more accurate term to signify *such things as are composed of matter;*—and the word employed for this purpose by natural philosophers is—*body*.

7. As the child grows older, experience teaches him that all the matter which he has been able to examine, is collected into *bodies;* and in after life he arrives at the conclusion that the whole created universe of matter is but a collection of a multitude of bodies.

8. The word *body* is a relative, rather than a positive term: That is:—It may be applied either to a single portion of matter viewed by itself, or to a number of portions of matter collected together in one *object*—one separate *thing*. A stone, a rock, a man, a fly,—each of these things is *a body:*—but a vast number of stones, rocks, &c., are required

to make up *the world*, yet, when we speak of the entire world as complete in itself, we may call it *a body*. The only reason why we cannot properly apply the term body to the whole material universe is, that the human mind cannot conceive of any limit to the material universe; and we are unable to comprehend anything complete in itself which has no known shape or *figure*.

9. As the child grows older, he finds that not only his toys, but even walls themselves are subject to changes of position;—that the very ground on which they stand—the world and the heavenly bodies, and, in short, all material things are in continual motion;—they are never absolutely at rest. From this, the conclusion is inevitable, that *mobility* is a general property of matter.

10. Though the house and everything in it is always moving with the world on which it stands, the relative position of the various articles of furniture is not changed by this motion, and these articles are said to be *relatively at rest.* Our young philosopher finds that the chairs or fender will not change their place of their own accord, but that some *force* is necessary to move them; and his after experience teaches him that this also is a quality of all bodies without distinction. He finds that when a ball of thread or spool of cotton is once put in motion by any force, the rounded body generally continues to roll until it reaches some *impenetrable* barrier. If the child attempts to stop its progress, he discovers that it is disposed to go on, and actually strikes a blow against the hand that opposes it. Some *force* is necessary to arrest it. Later in life he learns a truth which often acts as a great stumbling-block to young beginners;—namely: that *all bodies*, when once put in motion, would go on moving in the same direction for ever, unless bent from their course or brought to rest by the application of some force in opposition to them. A body in motion has no power to change its route or stop of itself. The property by which all bodies preserve their existing condition of motion or rest until that condition is changed by the application of *force* is termed *inertia*.

11. When a child first succeeds in breaking some of his playthings, he finds that *divisibility* is one of the properties of these bodies; after experience teaches him that all other bodies are divisible in the same manner. No material thing so tough or so hard as to resist this law has ever been discovered. *Divisibility* is, therefore, one of the general properties of matter.

12. It is impossible to find any limit to the divisibility of matter. After having broken a body to pieces, we can grind it to powder so fine that the *particles* become invisible and may be blown away by the breath; and so long as a particle continues to be distinguishable by any of the senses it may be still further divided.

13. Next among the important general properties of matter is *gravity*. Every one knows that when a stone is hurled into the air, it rises more and more slowly until it is brought *relatively* (10) to rest; but the instant this is effected, it commences falling toward the earth, and continues to fall faster and faster, until it is arrested by the ground, or some other impenetrable barrier. In climbing upon a tree, if a lad venture far out upon a slender limb it bends or perhaps breaks; and the young experimenter finds himself subjected to the same accident as the stone. He is precipitated to the ground. When a body of considerable size is held in the hand, an effort is necessary to prevent it from falling also. These facts plainly show that stones, children and other heavy bodies, if left without support have a constant tendency to approach the earth, and that force or resistance is necessary to prevent their following this inclination. This tendency is in full action even while the body exerting it is rendered immovable by a solid support; for if we attempt to raise a stone from the ground we find it necessary to apply to it at least as much force as is required to prevent it from falling after it is raised. Hence the stone presses the ground with as much force as the hand presses the stone. Clouds, balloons, &c., and light bodies when under water, furnish apparent exceptions to the rules just mentioned; but we shall find, hereafter, that these bodies also have the same inclination to approach the ground, though prevented from displaying it because they are really *supported* by means which the young reader is not yet prepared to understand.

14. The tendency of bodies to approach each other from a distance occasions innumerable curious effects, not confined to the world in which we live; and convenience requires some single word or term to express this tendency. The word employed for this purpose is *gravity*.

15. The mind of man cannot conceive the occurrence of any *event* without *a cause*. Although no philosopher can explain why a stone falls to the ground, we are compelled to believe that there is a cause of gravity: and as bodies when gravitating appear to draw each other together by a mutual action, the unknown cause of this class of events has [illegible] called the *attraction of gravitation*.

16. The Earth is a large body, nearly globular, and about 8000 miles in diameter, or about 24,000 miles in circumference. Mountains upon its surface are like grains of sand in proportion to its vast bulk, and little ponds or pools of quiet water which occur in all countries, present us with an abundance of smooth surfaces agreeing exactly with the general form of the globe, but, from their small size when compared with the vast magnitude of the earth, they may be considered, for all purposes of experiment, as perfectly level. They enable us to judge with great accuracy the direction in which bodies near the earth are drawn or *attracted* towards it by gravity. If we tie a heavy substance to the extremity of a slender thread, and let it hang freely from some fixed object, it will soon settle by gravity into such a position that the direction of the string will be immediately towards the surface of standing water. This is found to be the case wherever the experiment is tried. Now, let Fig. 1 represent the earth, and A, B, C, and D, four observers, each holding the string and cord just described, which is called a plumb-line. These lines each tending directly towards the surface of the earth at the spot where the holder is placed, their several directions will be represented by the dotted lines in the figure. But all lines drawn directly towards the surface of a sphere, if continued, will meet at a certain spot within the sphere, as the four lines in the figure are seen to do. As the course of the plumb-line clearly marks the direction of gravity, it follows that all bodies near the earth must gravitate towards this one spot, unless influenced by some other force besides the general attraction of the earth.

Fig. 1.

17. This fact in relation to the direction of terrestrial gravitation, together with the use of the plumb-line, enables us to prove that not only the whole earth, but each of its parts possesses the attraction of gravitation.

18. It is evident that the plumb-line points not only to the spot within the earth of which we have spoken, and which is called the centre of the earth, but also to that spot in the heavens which is directly over head, and is called the *zenith*. As the stars appear to sweep onward in their path, many of them approach near to the zenith, and it is easy,

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moved or changed in position; 4. *Inertia*—(10) the tendency to remain in motion or at rest without change, except when acted upon by some *force;* 5. *Divisibility*—(11, 12) the capacity to be separated into parts; and 6. *Gravity*, which will be more thoroughly understood hereafter.

EXTENSION.

21. *Limits or Boundaries of Bodies.*—The universe of matter is composed of a multitude of bodies (8), each occupying a definite portion of space; and there exists no *material thing* without limits or boundaries, which prescribe its *form* or shape.

22. The boundaries and forms of bodies have their peculiar properties or relations, as well as the bodies themselves and the matter of which they are formed. As it is impossible to obtain any clear idea of the action of bodies on each other without some knowledge of these properties of forms and boundaries; the pupil, if unacquainted with the principles of geometry, will be obliged to make himself familiar with a few of them before proceeding in his studies.

23. Every one knows what we mean by the point of a pin or needle; but a much clearer idea of the philosophical meaning of the term *point* is required by the pupil. Under a strong magnifying glass, the extremity of the most delicate needle looks rough and irregular: it occupies considerable space, and thus we find that even the "point" of a needle does not "come to a point." But we can well conceive that if our art were sufficiently perfect, and the nature of matter admitted of such an accomplishment, we *might* sharpen a needle "away to nothing." That *nothing* would be a *point*, in the sense in which the word is used by natural philosophers.

24. Supposing that we could make a needle perfectly sharp, its point would always preserve the same *position* in relation to the needle itself; but, as it would occupy no space, it could not be measured—*it has no dimension.* From these properties we derive the best definition which can be given of this important abstract idea of the mind. A point is *that which has position, but no magnitude.*

25. A point is not a property of matter, but of space; and when we use the term in speaking of the boundaries of bodies, it has relation not to the bodies themselves, but to the portions of space which they occupy. Thus: the point of a needle is not the extremity of the needle itself, but the extremity of the space which the needle happens to occupy.

Even if the needle should cease to exist, the space which it occupied would still remain, and the termination of that space would be a point. It is not so very wonderful, then, that a given portion of space,—which has no material existence—should terminate in a point which is nothing.

26. As examples, it is well to mention that the corners of the space occupied by a chest or table, where several sides meet, would be points, if the sides of these bodies were perfectly smooth; the exact middle of a round and globular body or figure is a point. The spot marked C, Fig. 4, represents a point, because it represents the middle of the figure, which is round. The middle of any distance between two bodies, such as the Sun and the Earth, is also a point. In fact, as a point is simply a position and takes up no room, points exist everywhere.

Fig. 4.

27. In common language the term *line* is applied to a cord, a driving rein, a rope, or anything that is long and narrow; but a much clearer idea of the philosophical meaning of the word is necessary for the students of philosophy. Suppose that the wagon wheel represented in Fig. 5, is rolled straight forward along the road from A to B; it is evident that the exact middle of the round space occupied by the wheel, which is a point, (23) must move in a straight direction as far as the distance from A to B. This distance and direction are represented by the long dots extending from the middle of the wheel in the first position to that seen in the second position. The middle point of all round or globular bodies is called the *centre*. The centre of the wheel, then, while thus rolling is said to *describe* the straight line A, B.

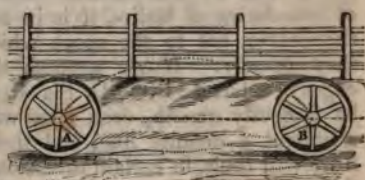


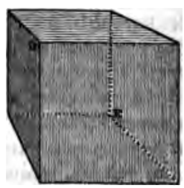
Fig. 5.

28. But it is very important that you should not mistake the dots that *represent the line* for the line itself. The dots, however fine they may be made, are composed of matter and

must therefore occupy space; but the point which describes the line is not composed of matter, and occupies no space—no width—and of course the line which it describes can have no width: it can occupy no space,—it can have no material existence, and possesses but one dimension—*length*. It existed in the same place, before the wheel *described* it, and must continue to exist when the wheel is totally removed. It existed on the paper before the figure was drawn, and would continue to exist if the figure were obliterated. You are now prepared to understand what is meant by the mathematical definition of this abstraction of the mind. A *line* is simply—*length without breadth.*

29. It is evident that the line A, B, may be extended or *produced* in either direction to any distance; and, if we take the imagination for our guide, it may be conceived to extend for ever or to infinity. The dots which represent a definite portion of it are bounded by the paper, but we may follow it mentally, until it sweeps beyond the paths of the planets, and, leaving the last visible star behind, buries itself in the immensity of space. Such portions of lines as we are able to measure are called *definite lines*, to distinguish from the whole lines, which have no known limits, and are therefore called *indefinite.*

30. The line, like the point, is a property of space, and not of matter; and when we use the word *line* in speaking of boundaries of bodies, it is in relation not to the bodies themselves, but to the space which they occupy. If we suppose the edges of a box A, B, C, D, Fig. 6, to be perfectly smooth, each edge will represent a definite line, and these lines will limit, in certain directions, the portion of space occupied by the box. Let the box be then removed to another place. It is plain that the same portion of space still exists, and that it has the same dimensions. The lines A B, B C, &c., are not removed, but we have only carried the box away from them to occupy another portion of space, bounded by other and similar lines.



C B A

Fig. 6.

31. The habit of considering points and lines as things belonging to matter is the greatest cause of difficulty with young persons who are commencing any study connected with natural philosophy.

32. *A straight line is a line which everywhere pursues*

the same direction; and ***a definite straight line is the shortest distance between two points:*** as A B, Fig. 5; but if the carriage to which the wheel represented in that figure is attached, be in the act of turning round upon the road while it is passing from A to B, the centre of the wheel will describe a line somewhat like that represented by the row of short dots in the figure. If you take any two points throughout the whole length of this line, you find that the tendency or direction at one of these points is different from that observed at the other. Such a line is called a *curved line.*

33. When the change of direction of a curved line follows any fixed law or rule, which will enable us always to draw a correct representation of the same or any similar line, the curved line is usually called simply *a curve*, to distinguish it from a mere crooked line which we cannot describe in words. Let us take some examples.

34. Drive a pin into a board at some convenient spot; as at A, Fig. 7; tie a string into a little loop; cast the loop over the pin; then take a second pin, and with it stretch the loop tight, in any direction; as towards B, in the figure. Now carry the second pin all around the first, still keeping the loop stretched, and make a mark on the board by scratching as you proceed. This mark will represent the line described by the extremity of the moving pin, and this line will be curved. Its form is seen in perspective in Fig. 7, and in direct view in Fig. 4. In this case, the loop governs or gives law to the curved line; for, it compels the extremity of the pin B to preserve at all times the same distance from the point of the pin A, Fig. 7. It follows, that all parts of this curved line are equidistant from the centre, and that all lines passing from the centre to the curve are equal to each other. Such curved lines are called *circles.* Here, then, we have a property of the circle without which it cannot exist, and which cannot belong to anything else. Such a property fixes, determines, or governs most absolutely, the character of this *curve;* it is therefore called a *law.* That is:—we say *it is a law of the circle that all lines drawn from the centre to the curve are equal to each other.*

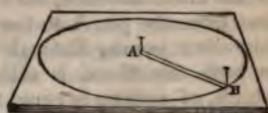


Fig. 7.

35. This word *Law*, as used by philosophers, generally conveys to beginners the idea of a written or spoken rule

for the government of things, instead of a mere short term that we apply to any particular class of facts in nature, which we find to be always true. A very few illustrations will remove this error. In the last section you were told that all bodies had a tendency to approach each other, and that this tendency was called *gravity* (14). Gravity, then, is a *principle* regulating matter—it is a *property* of matter—a *law* of matter. We know that any body, if put in motion, will continue to move on in a straight line, unless bent in its path or stopped *by force.* (10) This is a *principle* regulating motion—it is a *property* of matter in motion—it is a *law* of motion. It must never be forgotten that, in philosophy, the words principle, property, and law are used to express exactly the same thing. William's eyes are gray—it is a principle in his constitution: Mary's are blue—it is a property of hers: James is blind—it is a law of his organization: all men have eyes—this is a property or law of human nature.

36. The word *circle* is used not only to signify the regular curved line described, but also, and even more commonly, to signify *the space inclosed within the line.* When the word is used in the latter sense, the curve itself is called the *circumference* of the circle. Any line passing from the centre to the circumference, such as the line from the pin A to the pin B, Fig. 7, is called a *radius.* Any line passing through the centre, to the circumference in both directions, is called a *diameter*, or *the diameter*, which, of course, is equal to two radii.

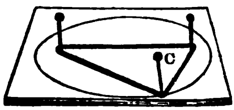


Fig. 8.

37. If, instead of the first pin in the last experiment, we take two, and drive them into the board as represented in Fig. 8, 9, and then throw a similar loop of thread over both pins, we may take a third pin, C, and by carrying it round the others, still keeping the loop upon the stretch, may scratch another kind of regular curve, such as that seen in perspective in Fig. 8, and directly, in Fig. 9. A curve of this nature is called an *ellipse.* The two points, A and B, where the fixed pins enter the board, are called the *foci.* Now this is a law of the ellipse:—Take any two points in

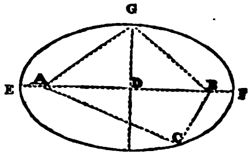


Fig. 9.

the curve, such as G and C, Fig. 9, and draw lines from each *focus* to each of these points; and the two lines drawn to the one point are exactly equal to the two lines drawn to the other point:—that is to say: A G and G B, added together, are exactly equal to A C and C B added together. If you gradually place the foci farther apart, while using the same loop, the ellipse will become narrow, until the loop, being fully stretched upon the fixed pins, the moveable one is compelled to travel directly from one focus to the other. The ellipse then becomes a definite straight line, with what were the foci forming points at its extremities. If you gradually place the foci nearer together, the ellipse will become broader in proportion to its length, until the two fixed pins touch each other. Then remove one of the pins, and the two lines drawn from the foci to the curve, become one straight line, which is a radius, (36); the two focal points become one single point, which is a centre, (34); and the ellipse is converted into a circle. In Fig. 10, you may observe three ellipses enclosed in a circle, all these curves being reduced from figures drawn with the same length of loop, but around different foci. The two outermost dots represent the foci of the narrowest of these ellipses, the next pair of stars are the foci of the middle ellipse, the innermost pair are the foci of the largest ellipse, and C is the centre of the surrounding circle.

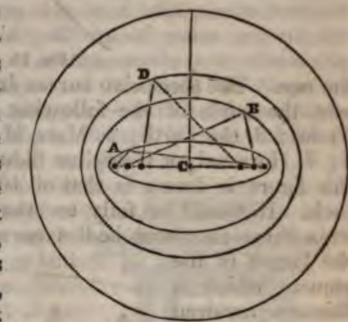


Fig. 10.

38. The longest line, or the greatest length of the ellipse, is called its *longitudinal diameter*:—E, F, Fig. 9. The longest measure of the breadth of the ellipse is called its *transverse diameter*;—G, H, Fig. 9.

39. This curve is of great importance in natural philosophy; for the motions of the earth and all the heavenly bodies appear to be regulated by the law of the ellipse. The earth and planets revolve around the sun, each in its own ellipse, which is called its *orbit:* and the sun is situated in the common focus of all these ellipses. Fig. 11 will give a rude idea of the distances of the several principal planets from

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14. The tendency of bodies to approach each other from a distance occasions innumerable curious effects, not confined to the world in which we live; and convenience requires some single word or term to express this tendency. The word employed for this purpose is *gravity*.

15. The mind of man cannot conceive the occurrence of any *event* without *a cause*. Although no philosopher can explain why a stone falls to the ground, we are compelled to believe that there is a cause of gravity: and as bodies when gravitating appear to draw each other together by a mutual action, the unknown cause of this class of events has been called the *attraction of gravitation*.

16. The Earth is a large body, nearly globular, and about 8000 miles in diameter, or about 24,000 miles in circumference. Mountains upon its surface are like grains of sand in proportion to its vast bulk, and little ponds or pools of quiet water which occur in all countries, present us with an abundance of smooth surfaces agreeing exactly with the general form of the globe, but, from their small size when compared with the vast magnitude of the earth, they may be considered, for all purposes of experiment, as perfectly level. They enable us to judge with great accuracy the direction in which bodies near the earth are drawn or *attracted* towards it by gravity. If we tie a heavy substance to the extremity of a slender thread, and let it hang freely from some fixed object, it will soon settle by gravity into such a position that the direction of the string will be immediately towards the surface of standing water. This is found to be the case wherever the experiment is tried. Now, let Fig. 1 represent the earth, and A, B, C, and D, four observers, each holding the string and cord just described, which is called a plumb-line. These lines each tending directly towards the surface of the earth at the spot where the holder is placed, their several directions will be represented by the dotted lines in the figure. But all lines drawn directly towards the surface of a sphere, if continued, will meet at a certain spot within the sphere, as the four lines in the figure are seen to do. As the course of the plumb-line clearly marks the direction of gravity, it follows that all bodies near the earth must gravitate towards this one spot, unless influenced by some other force besides the general attraction of the earth.

Fig. 1.

17. This fact in relation to the direction of terrestrial gravitation, together with the use of the plumb-line, enables us to prove that not only the whole earth, but each of its parts possesses the attraction of gravitation.

18. It is evident that the plumb-line points not only to the spot within the earth of which we have spoken, and which is called the centre of the earth, but also to that spot in the heavens which is directly over head, and is called the *zenith*. As the stars appear to sweep onward in their path, many of them approach near to the zenith, and it is easy,

14, supported upon a straight wire A B, and cause this instrument to move forward until the line A B corresponds with the line C D, the semicircular wire will describe the space A E B D F C: which space will also possess length and breadth, without thickness.

42. If, in Fig. 13, we lift the table up until its top exactly corresponds with part of the space A B C D, this portion of the space will be the *surface* of the table for the time being. But, in the picture, the table is represented with a different surface, situated lower down. This latter surface then is but a similar portion of space, and is therefore a property of the space occupied by the table, and not a property of the table itself. The term surface or *superficies* is applied to all such spaces as have length and breadth without thickness, whether defined by the presence of matter or not.

43. In flat surfaces, such as A B C D, Fig. 13 and 14, any straight line, or, as it is frequently called, "*right line*," drawn from one point to another will be entirely within the surface. Hence the following definition. *A plane surface* is that in which any two points being taken, the straight line between them lies wholly within that surface. Such surfaces when considered indefinitely, are usually called simply —*planes*. But if, in Fig. 14, you were to draw a right line from A to F, two points in the surface described by the semicircular wire, this line would not "lie wholly within that surface." Such surfaces are either *curved* or *irregular*.

44. Though we cannot in reality move either points, lines or superficies, it is sometimes convenient to suppose them capable of motion. Thus, instead of supposing the ruler or the wire in Fig. 13 or 14 to be moved from A B to D C, we may as readily suppose the line A B itself to undergo this motion; and now that the nature of such abstract ideas as the point, the line, and the surface, have been fully explained, we may venture to employ this style of language in relation to such subjects.

45. Let A B E H, Fig. 15, be a definite plane surface, seen in perspective. Let it be gradually lifted up in the direction of the line B C, until it lies in the same plane with the surface C D F K. This surface will then describe the whole figure A B C D F H, having six sides or surfaces determined. Here, then, we have a definite portion of space, having three different dimen-

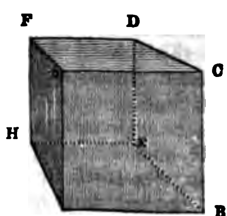

Fig. 15.

sions, *length, breadth* and *thickness.* There is *room* within this space of three dimensions for the reception of *matter.* Were we to fill up this figure or space with lead, it is evident that we should have a solid body of lead with six sides, bounded by the same surfaces as those of the figure; and as we have no peculiar word by which to express the space alone, when unoccupied by matter, the term *solid* is often applied to the figure as well as the substance. In speaking of the properties of *space*, then, *a solid* is *a portion of* space, having three dimensions—*length*, *breadth* and *thickness.*

46. As the boundaries of surfaces are lines, and the boundaries of solids, *and therefore of bodies*, are surfaces, it is necessary to be acquainted with certain relations of lines and surfaces to each other in order to comprehend the relations between bodies which constitute the proper study of the Natural Philosopher.

47. When two straight lines lying in the same plane have such directions that, though produced indefinitely, they can never meet—that is when they are equi-distant from each other throughout their whole length,—they are said to be *parallel* to each other, and all straight lines which are parallel to the same straight line are parallel to each other.

48. It is evident that a straight line may be parallel to a plane. Thus the lines running lengthwise on the cornice or surbase of a room are all parallel to the surfaces of the ceiling and the floor; because if produced indefinitely, such lines and such planes can never meet. One plane may also be parallel to another plane for similar reasons.

49. When straight lines lying in the same plane are not parallel to each other, they must meet somewhere. Let C D, E F, and G H, Fig. 16, be three definite lines that are not parallel to the line A B, though in the same plane. If all these lines be produced both ways, each of them must *meet*, *cross* or *cut* the line A B at some point. Produce C D and G H, and you find that C D meets A B at B, and that G H meets it at A.

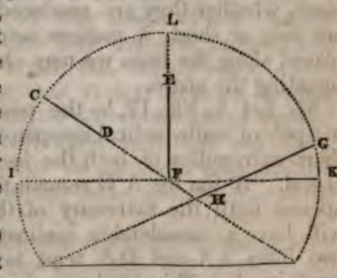

Fig. 16.

50. There are few ideas more puzzling to beginners than that which we express by the word *angle;* and it is necessary that it should be perfectly understood by the student.

We will here endeavour to explain it. *An angle is the tendency of two lines or surfaces towards each other.* Thus; the tendency of the right line C D, Fig. 16, to meet the right line E F, is an angle. This tendency exists at all times, whether the definite lines do actually meet or not; for, as all lines are in their nature unlimited in the extent, the lines of which the definite portion E F and C D are merely parts, do actually meet in space, whether we draw or represent them or not. Let us consider the line C D as produced until it meets E F in the point F. The two lines are then said to *meet at an angle.* When we wish to speak of any particular line or angle, the point at which the lines meet is called *the angular point,* and in each figure of an angle it is usual to place some letter at this point, by which to designate it. Where there are but two lines meeting at any angular point; as at F, Fig. 16; it would be sufficient to say simply the angle F, when speaking of the inclination of these two lines: but there are more than two lines meeting at F, and something more is necessary to determine whether we speak of the tendency of C D towards E F, or that of K F towards E F—the angular point being the same for both. To avoid this difficulty we commonly use three letters to express an angle, or tendency of two lines to meet each other. One of these letters is chosen from each of the lines to which we refer, *but the letter at the angular point is always placed in the middle.* Thus; when we speak of the tendency of C D and E F to meet, we say, "the angle C F E," or "the angle E F C;" or, with equal propriety we may say "the angle D F E, C F L, or L F D;" for, as the inclination or tendency of the lines to meet is always the same, whether they are produced or not, and whether they are long or short, it matters not what letters happen to be placed along the lines we may choose for the purpose of designating the angle.

51. Let A, Fig. 17, be the position of the central point in a pair of mathematical compasses, and D the position of the sharp extremities of both the legs, when the instrument is closed. If the leg A D remain fixed, and the instrument be opened until the extremity of the other leg reaches B, it will have a considerable inclination towards A B, and the two lines B A and D A tend towards each other, so as to meet in A. This tendency is the angle B A D. If we open the compasses gradually until the extremity B coincides with the point E, the angle between the lines B A and D A will become greater and greater until it forms the

angle E A D. Hence we may say that the angle E A D is greater than either the angle E A B or the angle B A D.

Fig. 17.

52. It is impossible to make these two lines approach other more directly than when the extremity B has reached the point E; because the line E A then runs direct or *right* towards the line D A, without inclining to either side in the slightest degree: and if we produce D A to K or further, it is equally evident that E A tends direct or *right* towards A K,—for D A and A K are in the same straight line: Hence the angles E A D and E A K are exactly equal to each other. The angles between two different straight lines which tend directly towards each other are called *right angles*, and the lines which form these angles are said to be perpendicular to each other. Thus, in Fig. 17, E A is perpendicular to D A or D K, and D A or D K is perpendicular to E A.

53. When an angle is less than a right angle it is called an *acute angle*. But we may open the compasses still further, after the extremity D has reached E. Let them be opened until the extremity B reaches G. Then the tendency of the two legs to meet may be measured either by the angle G A K, which is the inclination of the moving leg towards the line D A produced, or by the angle G A D, which is the inclination of the two legs towards each other. Of these angles, G A K is much less than a right angle, and is therefore quite acute, but G A D is much greater than a right angle:—Such angles are called *obtuse angles*. If we open the compasses still wider, until the extremity B coincides with K, there will be no angle between the two legs, for one will be in the same straight line with the other.

54. It is now time to describe the mode of measuring angles. If we could carry the moveable leg of the compasses all the way round until the extremity B should return to the point D, the extremity B would describe an entire circle, with A as the centre, and one leg of the instrument as radius. The legs of the instrument would tend towards

each other at every possible angle at different times, and the portion of the circumference of the circle embraced between their extremities at any one time would be a measure of the angle for the moment; thus: the portion of the circumference from B to D is the measure of the angle B A D; and the portion from D to E, measures the angle E A D. Now any portion of the circumference of a circle, such as B D or B E G or D E G, &c., is called an *arc* of a circle. Hence, if we take either of two angular lines as a radius, and, with the angular point as a centre, describe a circle, the arc of that circle which intervenes between the lines will be a measure of the angle.

55. We measure angles, not by the length of the arc in inches, but by the proportional part of an entire circle drawn round the angular point that intervenes between the lines: and as this proportional part is always the same, whether the circle itself be large or small, it matters not what circle we employ to compare the dimensions of several angles with each other, provided we use circles of the same size in each case.

56. As we cannot express the dimensions of an angle by any lineal measure, such as feet or inches, we require a peculiar set of relative terms for this purpose. The object is obtained in the following manner: The circumference of every circle, whatever may be its size, is considered as divided into three hundred and sixty equal parts called degrees, and written thus: 1°, *one degree*; each degree is divided into sixty parts called *minutes*, and written thus: 1′, one minute;

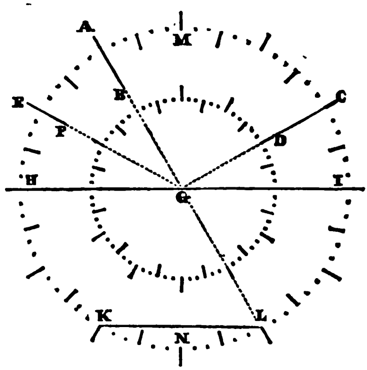

Fig. 18.

each minute into sixty parts called *seconds*, written thus: 1″, one second. The larger the circle the longer are the degrees, but the *number* never varies. Fig. 18 presents two circles of different sizes, divided or *graduated* in such a manner that each interval between the dots is equal to 5°. In order to measure the dimensions of the angle formed by any two straight lines, take the angular point as a centre,

and with any convenient radius, describe a circle, and divide the circumference into 360 degrees. The number of degrees contained in the arc between the lines will be the measure of the angle. In Fig. 18, the three definite right lines A B, C D, E F, all tend to meet the straight line H I, in the point G, which is the angular point of all these lines and has been made the centre of the two graduated circles. Whichever circle you choose for your measure, you perceive that of the three angles H G E, E G A, C G I, each counts 30°, while the angle A G C counts 90° and is therefore three times as large.

57. There is no better way of lightening the labour of these apparently dry studies than by showing their usefulness. Now, therefore, let the inner circle be a representation of the earth, with G as one of the poles, and the points immediately beneath the letters F, B, and D the positions of three observers. Suppose a star to be placed at E, exactly at the zenith of the observer F, at twelve o'clock at night. When will that star become *vertical* or reach the zenith (18) of the observers B and D? The Earth revolves from west to east through its whole circumference of 360° once in about 24 hours. It therefore moves through one degree in about four minutes of time. At this rate, it will take just 2 hours, or 30 times 4 minutes, to bring the observer B under the star at E; the angular distance being 30°: and 8 hours or 120 times 4 minutes will be required to bring D to the same situation; the angular distance being 120°. Thus when it is *noon* to F, it is two hours before noon, or 10 o'clock A. M. to B, and 4 o'clock A. M. to D. This is in fact the mode in which astronomers and geographers calculate the hour at different places at the same moment.

58. The line A L, which runs through the centre completely across the circles, in Fig. 18, has 180° or half the circumference on each side of it; but the line C G meets A L in such a manner that each of the angles A G C and C G L measures 90°, or one fourth of the circumference: so that the line C G meets the line A L in such a manner as to make the adjoining angles equal: Therefore these lines are perpendicular to each other, and the adjoining angles are right angles; (52) and whenever a line meets another at an angle of 90° the angle is a right angle and the lines are perpendicular to each other.

59. In making diagrams we frequently have occasion to draw lines that will make angles of a certain given number of degrees with each other. For this purpose it is customary

to form a scale from some one circle, by which we may measure and compare all possible angles; and this is done in the following manner: A straight line extending from one end of any arc to the other, is called a *chord*. Thus; K L, Fig. 18, is the chord of the arc L N K. This arc contains 60°. K L is therefore the chord of sixty degrees. Now, if the circle were twice or thrice the size given, the arc would still contain the same number of degrees, and those degrees as well as the chord would be accordingly twice or three times as long as they are in the figure. That is to say; the length of the chord of any given number of degrees varies in different circles in exact proportion to the length of the arcs, or to that of the radii. Therefore, take any circle of convenient size and divide its circumference into 360 equal parts or degrees, then measure the chords of every one in succession, from 1° to 90°, and lay the measurements down on a scale of ivory or metal; as in Fig. 19; where you see marked the chord of every degree as far as 10°, and thence of every ten degrees to 90°.

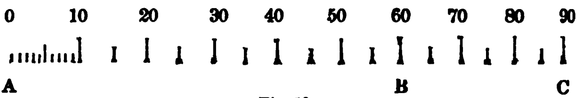

Fig. 19.

60. It happens that in every circle the chord of sixty degrees is exactly equal in length to the radius of that circle. If then you wish to measure any angle by means of the scale of chords, take the chord of 60°, or the line A B, Fig. 19; use this as a radius, and the angular point as a centre, and describe an arc of a circle from one line to the other. The chords on the scale will answer exactly to the degrees of this circle. It is then only necessary to measure with the compass the chord of the arc intercepted between the two right lines and apply this measure to the scale of chords from 0 toward 90, and the number of divisions of the scale embraced by the compass will mark the number of degrees contained in the angle.

61. One plane may form an angle with another plane. Let the plane A B E K, Fig. 20, represent part of a surface of a table, and the two planes B C D E, and F G H I, the surfaces of two plates of glass resting upon it edgewise. If C B, the edge of the glass, be perpendicular to A B, the edge of the table, then the plane B C D E will be perpendicular to the surface of the table; and the line C B will be also perpendicular to any and every line lying wholly

within the plane of the table that terminates in the point B. The same thing is true of every other line in the plane B C D E, that is drawn perpendicular to E B—the line of intersection between these planes. Therefore; if, in two planes that intersect each other, we choose any point in the line of intersection, and

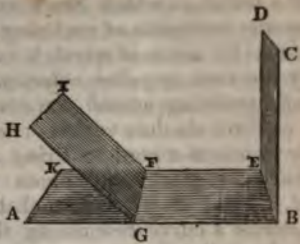

Fig. 20.

draw from this point two lines, one in each plane, making each of these lines perpendicular to the line of intersection, and if we find that the two lines thus drawn are perpendicular to each other, then the two planes are also perpendicular to each other. But if the two lines thus drawn are not perpendicular to each other, the two planes cannot be so, but must incline towards each other at an angle greater or less than 90°. In the two planes A B E K and F G H I, Fig. 20, the line H G in the latter plane is perpendicular to F G, the line of intersection, and the line A G in the former plane is also perpendicular to F G: but A G is not perpendicular to H G, though both lines terminate in the point G, which is in the line of intersection. Therefore the plane F G H I is not perpendicular to the plane A B E K, but is inclined to it at the angle A G H; the admeasurement of which in this case would be found to be 45°.

62. A single curved line may *enclose a space;* as in the circle: or a curved line and a straight line may do so; as in the semicircle: but not less than three straight lines are required for this purpose. Figures or spaces enclosed by three lines are called *triangles.* Those formed by right lines are called *rectilineal triangles,* and those formed by three curved lines, usually take the name of their peculiar curvation, thus: we have *spherical triangles, elliptical triangles,* &c.

63. But in order that a *regular* curved line (33) should enclose a space, it is necessary that it should always lie in the same plane. The wire of a common suspender spring can never enclose a space, because it never remains—even during a single turn—in the same plane, although the turns of the wire may be so close as to touch each other and form a tube. A curve of this character is called a *helix:* from the Latin word *Helix*—a snail. The line of the edge of a screw is a helix. The helix must not be confused with *the spiral,* Fig. 21,—a curve like that seen in the hair-spring

of a watch,—which lies always in the same plane, but is equally incapable of enclosing a space.

63. By means of spirals we can best illustrate what is meant by the term *angular velocity*. Let A, Fig. 21, be a little ball revolving around the centre B in the circle A C, with a uniform absolute velocity; being restrained from flying off by means of a cord or string A B. Then let this string be gradually shortened without arresting the circular motion of A, and it is evident that the centre of the ball will describe a curve resembling that represented in the figure. If the ball be made to pass through the first round of the figure and return to the line A B in exactly the same time which it occupies in performing the second and all other similar rounds, the curve will be a spiral exactly like that represented in the figure, and the body will have *a uniform angular velocity;* but in order to move in this manner, its *absolute velocity* must be continually retarded, or it must approach the centre B more and more rapidly; because it has a much shorter distance to travel during the second, than during the first round. If the string A B be uniformly shortened while the absolute velocity of A also continues uniform, the turns or whirls of the spiral around the centre B will be much more numerous, and they will also be placed continually nearer together as they approach this point. Meanwhile the angular velocity of the ball will be constantly *accelerated*, and this will give it the unreal appearance of moving with an accelerated absolute motion. The following experiment will fully explain this subject: attach a playing-ball to one end of a cord, three or four feet in length, and holding the other end in your left hand, take the string near the middle, between the thumb and finger of your right hand, and give the ball a whirling motion. Of course it will revolve nearly in a circle, if your hand moves steadily. Then, while it is in motion, draw the string through your fingers pretty quickly and uniformly with the left hand, so as to shorten

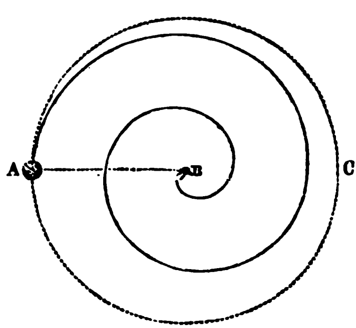

Fig. 21.

the cord. The ball will approach the hand as a centre, and will continue to move at nearly the same speed; but, having at each turn less distance to travel, it will perform its revolutions more rapidly, and will thus appear to be actually moving faster. If the ball A, Fig 21, while revolving, were made to approach the centre B with a very rapidly accelerated velocity, it might reach that point before it could even complete a single whirl, yet its line of motion would still be called a spiral. A spiral of this character is seen in Fig. 22.

Fig. 22.

65. It has been stated that at least three straight lines are required to enclose a space. But it is also necessary that the three lines should be in the same plane. Three or more such lines located in different planes, if they meet at all, can only meet at a single point, where they constitute a *solid angle*, thus: if the lines marking the direction of the inclined legs of a stool, as represented in Fig. 23, be continued until they meet in the air, as at A, they will form what is called a solid angle; because these lines are then the boundaries of a solid figure, formed by the intersection of three planes at the point A, and resting upon the plane surface of the stool as a base.

Fig. 23.

FIGURE.

66. The three angles of any rectilineal triangle are equal to two right angles, or 180°. If, then, a triangle have one of its angles a right angle, it cannot have another of as great dimensions, but the remaining angles must be acute. Such a triangle is called *a right angled triangle*, Fig. 24. If one of the angles be obtuse, the remaining angles must be still more acute than in the last case, and the triangle is termed *an obtuse angled triangle*, Fig. 25. It

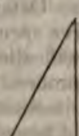
Fig. 24.

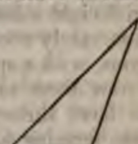
Fig. 25.

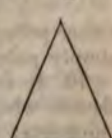
Fig. 26.

is only when each of these angles measures less than 90° (58) that the triangle is called *an acute angled triangle*, Fig. 26.

67. Triangles also receive different names from the different relations of the length of their several sides, thus: when all the sides are equal, the triangle is an *equilateral triangle;* when two of the sides only are equal, it is an *isosceles triangle*, and when all the sides are unequal it is called a *scalene triangle.*

68. Plane figures enclosed by four straight lines, are called *quadrangles* or *quadrilateral figures;* for, all plane figures bounded by straight lines have as many angles as they have sides. The following terms applicable to figures bounded by four straight lines being frequently employed by writers on natural philosophy, it is proper to define them here. 1. A *parallelogram* is a plane quadrilateral figure, with its opposite sides parallel. 2. A *rectangle* is a parallelogram, having all its angles right angles. 3. A *square* is a rectangle, having all its sides equal. 4. A *rhomb* or *rhombus* is an oblique angled parallelogram, having all its sides equal, and its diagonally opposite angles equal, but not right angles. Its shape is that of a lozenge. 5. A *rhomboid* is an oblique angled parallelogram resembling a rhomb, but having two of its sides shorter than the other two. 6. A *trapezoid* is a plane quadrilateral figure, having two of its opposite sides parallel, but the remaining sides inclined. 7. A *trapezium* is a plane quadrilateral figure, having no two of its sides parallel to each other. These figures require no further illustration.

69. As a convenient general term for plane figures with many sides we employ the word *polygon*, derived from two Greek words, signifying *many angles;* and, in giving names to the different figures according to the number of sides or angles which they contain, we preserve the same termination—*gon*,—coupled with the Greek word signifying the number of the angles in the figure; thus:

A figure with five sides is a Pentagon;
" with six sides a Hexagon;
" with seven sides a Heptagon;
" with eight sides an Octagon.

Other polygons rarely receive specific names, but are called simply polygons, with a specification of the number of sides.

70. It is now time to proceed to the consideration of figures which have three dimensions—length, breadth and thickness; thus forming solid figures. The simplest mode of explaining the most important of these forms, is to suppose that the plane figures already described are capable of being ‑ed in any direction through space, and considering

the character of the forms of space which each figure might thus determine.

71. The semicircle represented at Fig. 27, if made to revolve about its diameter, would carve out, or, as philosophers are accustomed to say, it would *generate* a figure like that represented in Fig. 28, which is called a *sphere.* As all parts of a semicircle are equi-distant from the centre, it follows that all parts of the surface, or, as it is termed, the *periphery* of the sphere, are equi-distant from its centre; and this is the *law* of the sphere.

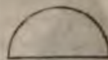

Fig. 27.

Fig. 28.

72. A line around which any thing is made to revolve is called the *axis* of its motion—thus, the middle line of the axle-tree of a wagon is the axis around which the wheels revolve. We also apply the same term to any line *along* which a body moves in a regular manner; thus, the string of a kite is the *axis* of the motion of the toy which children call *a messenger.* If then we choose the shorter diameter of

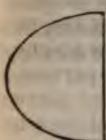

Fig. 29.

Fig. 30.

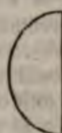

Fig. 31.

Fig. 32.

an ellipse as an axis of revolution, Fig. 29, the solid generated will resemble Fig. 30. This is called an *oblate spheroid* or *ellipsoid.* It is the figure assumed by our earth, and probably by all planetary bodies that revolve upon their axes. If we choose the long diameter of the ellipse, Fig. 31, as an axis, the figure generated will be one of much less importance in philosophy, called a *prolate spheroid* or *ellipsoid*, Fig. 32. In spheres and spheroids, the extremities of the axes of revolution are called *poles.*

73. If we suppose the right angled triangle, Fig. 24, to revolve around either of its two shorter sides, the solid generated will be a *cone*, Fig. 33.

74. If a parallelogram—Fig. 34—be supposed to revolve around one of its sides as an axis, the figure generated is called *a cylinder*—Fig. 35. Or, if a circle, Fig. 36, be supposed to move *along* an axis perpendicular to its surface, such as that represented by the dotted line in the figure, the solid *generated will also* be a cylinder.

Fig. 33.

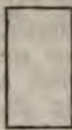

Fig. 34.

Fig. 35.

Fig. 36.

75. All solid figures that are bounded by parallelograms and have their opposite sides parallel are called *parallelopipeds.* Suppose the square figure seen unshaded and in perspective in Fig. 37, to move along the dotted axis C D, perpendicular to its surface, keeping always parallel to its first position, from A to B, the side A B being equal to one side of the square. It will then generate the solid represented by shading, and this solid will have six equal sides, all of which will be equal squares, and all the angles between its contiguous sides will be right angles. This figure is called *the cube.*

76. If, instead of a square, the generating parallelogram were an oblong rectangle, moving in the same manner, the solid would be *a rectangular parallelopiped, but not a cube;* for all its sides would not be equal. When the axis of motion of the square is not at right angles to its surface, but lies obliquely to it, and when the edges are all equal, two of the sides of the solid will be rhombs, and the figure will be *a rhombic parallelopipedon,* Fig. 38. Many *mineralogists* and other scientific men, call this solid and the plane rhombic figure by the same name — *rhomb.*

Fig. 37.

Fig. 38.

77. If the motion of the generating square along an oblique axis, as in Fig. 39, A B, be stopped before the edges of the solid become all of equal length, or if it be continued after that period, or, if the generating parallelogram be an oblong rectangle or a rhomboid, in each of these cases the solid generated will be *a rhomboidal parallelopiped,* because some of its sides will be rhomboids.

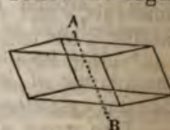

Fig. 39.

78. If any polygon be supposed to move along an axis, still keeping parallel with itself, the solid generated will be a *prism*: but this term is rarely applied to solids with six

Fig. 40.

Fig. 41.

Fig. 42.

Fig. 43.

sides unless when they are very long in proportion to their breadth. Fig. 40 represents a right three-sided prism with its generating triangle and axis; and Fig. 41, a right six-sided prism, with its generating hexagon and axis.

79. If we suppose any generating polygon to become uniformly smaller as it moves along an axis, keeping parallel to its first position, it is evident that it will describe a solid figure the sides of which will draw together continually until they come to a point. Such figures are called *pyramids*. In Fig. 42, you see a trilateral or three-sided pyramid with its generating triangle: and in Fig. 43, a quadrilateral pyramid with its generating parallelogram. As a polygon may have any number of sides, so may a pyramid or a prism. In speaking of the sides of a pyramid, the bottom or base is not counted; and in speaking of the sides of a prism, neither the top nor bottom is counted.

80. There are a great many solids with plane sides which are not included in any of the forms or figures of definite spaces of which we have been speaking:—that are neither pyramids, nor prisms—and it is convenient to have a set of terms to express these different forms. The scientific names of solids with many plane sides, follow the order of the Greek numerals, exactly as the names of plane rectilineal figures do (69); but instead of each name ending in *gon*, as is the case with the plane figures, the termination *hedron* is adopted to signify a solid figure. Thus: we have trigon, tetragon, &c., among plane figures; answering to trihedron, tetrahedron, &c., among solids.

81. When all the sides of any polygon or polyhedron are

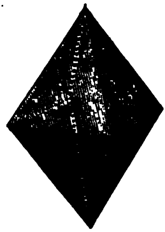

Fig. 44.

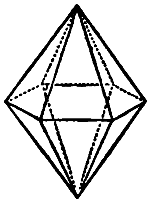

Fig. 45.

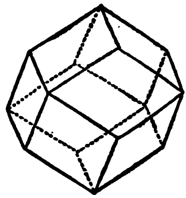

Fig. 46.

equal, the figure is said to be ***regular***. The examples of such figures are as follows. The tetrahedron is simply the pyramid with three sides, Fig. 42; the base being now counted as a side. The octahedron is formed by joining two pyramids with four sides base to base, as represented in Fig. 44. There are three kinds of regular dodecahedron——one, with twelve triangular sides, being two six-sided pyramids united by the bases, Fig. 45; one, with twelve rhombic or rhomboidal faces, called *the rhomboidal dodecahedron*, Fig. 46; the other with twelve pentagonal faces, called *the dodecahedron with pentagonal faces*, Fig. 47. The *icosahedron*, a figure with twenty triangular faces, is represented at Fig. 48.

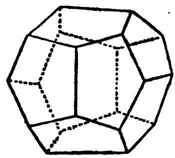

Fig. 47.

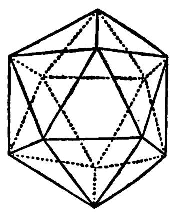

Fig. 48.

OF THE MEASUREMENT OF EXTENSION.

82. In measuring the distance between any two points, we perceive at once that we are estimating the amount of a *definite space*, and our minds very naturally refer to *feet* and *inches*, *miles*, &c., as suitable measures with which to determine the distance. From the popular use of the word measure, we are apt to think that when we estimate the extension of any body by what are called solid or fluid measures, such as the *bushel*, the *quart*, &c., we arrive at the *quantity of matter* in the body, while in fact we measure only *the quantity of space* which it occupies. By neglecting this distinction we might be led into ridiculous errors. *Weight* is a true measure of the force with which the matter contained in a body gravitates towards the earth, and as this

force depends upon the quantity of the matter contained in the body, weight must be a measure of that quantity; though it is no measure of the space which it occupies. A pound of water measures about a pint: the same water converted into ice measures considerably more, and boiled into steam, it measures many gallons, yet the ice, the water and the steam contain the same matter unchanged in quantity, and of course, in weight.

83. The true measures of space are either *linear*, having length only; *superficial*, having length and breadth only; or *solid*, having three dimensions—length, breadth and thickness.

84. *Lines can only be measured by lines.* Civilized nations of the European stock have generally adopted the linear inch as the unit, or basis of linear measure, and all other linear measures in use are mere multiples or parts of the definite length an inch.

85. *Surfaces can only be measured by surfaces.* The general unit or basis of superficial measure is the square inch, and all other superficial measures may be regarded as mere multiples or parts of a definite square surface, of which each side measures a linear inch. Let A B C D, Fig. 49, be a square, having each of its sides one foot in length, and divided into twelve parts or inches. It is very evident that the space constituting the surface of the square A B C D, can not be measured by the line A B, nor by the line A D, nor by any number of lines whatever; because a line *occupies no space*. You cannot multiply the line A B by the line A D. Yet, if you multiply the number representing the linear inches in the line A B—that is, *twelve*—by the number representing the linear inches in the line A D, which is also *twelve*, the result will be 144, the number of the square inches into which the great square may be divided.*

Fig. 49.

* In all arithmetical calculations, we deal with numbers only, and not with the things which they may be employed to designate. What is termed the *square* of any number is simply the product of that number multiplied by itself; and the *square root* of any number is that other number which when multiplied by itself, produces the former number. Thus 12 is the *square root of 144*, and 144 is the square of 12.

4

86. ***Solids can only be measured by solids.*** It is evident that no number of surfaces can form a solid, for surfaces have no thickness. Let Fig. 50 represent a cubic block of which each of the twelve edges measures one yard. Divide the lines A B, A C, B D each into three parts representing feet; and complete the division of all the visible sides of the cube into square feet. Now, by multiplying the number of the parts in A B, by the number of the parts in A C, you have $3 \times 3 = 9$—the number of the square feet in the side A F, and consequently in each of the other sides of the cube. But; if we should divide the block by planes passing through all the lines that cross the several sides, it is obvious that we should cut it into a bundle of little cubes, the sides of which would be equal to square feet; and of these there would be three rows in depth, each containing nine cubes. If, then, we take the numbers of the parts of one of the edges of this cube, which we may consider as representing its first dimension—*length*—and multiply this number by itself for the second dimension—***breadth***—and once again for its third dimension—***thickness***—we ascertain the measure of the contents of the ***cube*** in ***solid or cubic feet:*** thus: $3 \times 3 \times 3 = 27$, which is the number of cubic feet in a cubic yard. The terms cubic foot, cubic yard, &c., are applied to spaces of every variety of figure, because they are used merely as measures of the *quantity* of definite portions of space, which has no necessary relation to their form.*

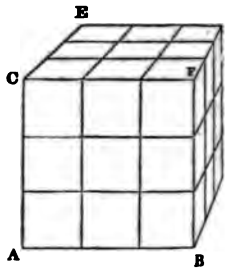

Fig. 50.

With these remarks we will conclude our observations on the properties and relations of extension.

DIVISIBILITY.

87. *Atoms.*—It has been already stated that we know no limit to the divisibility of matter. It requires 1800 leaves of thin gold-leaf to equal in thickness an ordinary sheet of paper. In gilding the silver wire used as the foundation of gold lace, the metal is reduced to much less considerable thickness; yet, when the silver is dissolved by nitric acid, the gold remains in the form of an exquisitely delicate tube, perfectly visible, and nearly opaque. By galvanic action,

* The cube of any number is the product of that number multiplied by its square.

films of metal so thin as to be transparent or invisible, may be deposited upon the surface of other metals; yet we have no proof that even these deposites are composed of single layers of particles.

88. Air, water, food, and even the fluids of our bodies teem with animal life. A single drop of water, containing a little vegetable matter and viewed under a strong microscope, often presents us with hundreds of living things of all sizes, from the giants and tyrants of their pigmy world to the mere animated dot, scarcely visible by the aid of the most powerful instruments. The largest of these display the passions and the instincts. They lie in wait for their prey, seize it by stratagem, and often contend most furiously for its possession. Chemistry proves that these diminutive beings are composed of matter resembling that which forms our own persons; and we know that they digest their food and perform many other acts which require in us a complex structure. How incalculably small must be the particles composing the frames of the smallest of these animalcules! Yet we are by no means certain that there may not exist within them, other beings still more minute.

89. Equally extraordinary are the phenomena of odorous substances. The perfume of a grain of musk will be perceived for years throughout a large apartment, without any considerable diminution of its weight; yet during the whole period it must perpetually throw off minute particles of its substance. A grain of blue vitriol, dissolved in one gallon of water, gives to the whole a visible blue colour. Now there are about 102,400 drops in a gallon of water. The tenth part of a drop of that mixture is distinctly visible, and will display the colour. Here, then, we actually see about the millionth part of a grain of blue vitriol.

90. Many philosophers in attempting to reason upon this indefinite divisibility of matter, venture beyond the bounds of reason, and confusing *matter* with *space*, assert that there are no particles of matter so small as to be indivisible into parts. If this were true, matter could not be impenetrable, but might be divided and re-divided until reduced to *nothing*. The human mind is not so constituted as to receive this monstrous doctrine until weakened by the false pride of speculation that leads some worthy people far beyond the bounds prescribed by Providence to human understanding; and it is now universally granted that in dividing any body continually, we should at last arrive at particles so hard and unyielding as to defy all our efforts. These inconceivably

minute particles are termed *atoms;* and it is believed that by collections of innumerable atoms the universe of matter is ultimately formed.

91. Notwithstanding the extreme minuteness of atoms, which will probably for ever prevent us from seeing them, we are able to study and experiment upon their properties, and can even furnish plausible reasons for attributing to them certain definite forms. By dividing various crystals in a peculiar manner, the mineralogist arrives at a rational conclusion with regard to the shape of their smallest possible particles. Having discovered this shape in any particular crystal, he not only proceeds to explain how all known forms of crystal observed in the same kind of matter are built up by the slow deposition of layer after layer of particles of similar shape, though in various orders, but can also determine in many instances, the nature of the substance composing a crystal of totally novel form, simply by measuring the proportions of its figure. The method by which we are able thus apparently to estimate the shape of invisible things is readily explained.

92. When we attempt to remove a brick wall by displacing the bricks layer after layer, we meet with comparatively little opposition from the softer cement or mortar, and we leave a tolerably smooth surface wherever a brick has been displaced. But when we attempt to divide the wall crosswise through the texture of the bricks, the opposition is enormously increased, and the surface is everywhere studded with rough projecting edges and angles. Thus, when we divide a crystal, it separates most readily and smoothly in those directions which correspond with the divisions between the successive layers of particles composing the crystal: but if we attempt to divide it in any other direction, the crystal seems much harder and the surface of division or *fracture* appears rough and irregular.

93. If you apply the edge of a sharp knife in a direction parallel to either side of a cubic crystal of rock salt, and strike it by a light, quick blow, the crystal will be divided by a plane parallel to the side of the cube. In this way, successive slices of equal thickness may be continually cut off parallel to every side of the cube, without changing its shape or leaving a rough surface. But if the edge of the knife be placed obliquely to the sides of the cube, the resistance is found to be much greater, and the fracture is very uneven; thus proving that you are cutting *across the arrangement of the particles.* It appears, from these circumstances, that the form of the par-

ticles of which crystals of rock salt are constructed is the cube; and hence the particles of all salt are regarded as cubical. No matter what form the crystal of salt may assume, it can always be reduced to the cube, by this mode of cutting, or,—as the mineralogists term it—by *cleavage.* The cube is therefore called *the primitive form* of the crystal of rock salt.

94. One of the most common forms of the crystal of fluor or Derbyshire spar is also a cube; but it is easy to prove that this figure is not the form of its particles or primitive form. If we divide a cube of fluor spar, Fig. 51, in a

Fig. 51.

Fig. 52.

direction parallel to its sides, we find that we are cutting across the course of the particles; but when we strike off the corners in the direction represented in the figure, we cut in the direction of the layers, and the fractures are smooth. Successive slices of equal thickness may be struck off from each of the corners, in directions parallel to the oblique planes in the figure, until all the sides of the original cube are cut entirely away, and the fluor spar is reduced to the form of the regular octahedron, Fig. 52. Whatever may be the figure of a crystal of this substance, it can always be reduced, by cleavage, to that of a regular octahedron; which is, therefore, the primitive form of fluor spar.

95. All known crystals that have been subjected to cleavage have been reduced to one or another of the following six primitive forms. 1. The parallelopiped, including the cube, rhomb, and rhomboid, Figs. 37, 38, 39. 2. The octahedron with triangular faces, Fig. 44. 3. The regular tetrahedron, Fig. 42. 4. The regular hexahedral prism, Fig. 41. 5. The dodecahedron with rhomboidal faces, Fig. 46. 6. The dodecahedron with triangular faces,—a figure formed of two hexahedral pyramids united at the base, Fig. 45. Of these forms, the cube, the regular tetrahedron, and the regular hexahedral prism can never change, but in each

of the others, the proportions of sides or angles may vary to an unlimited extent, giving rise to a multitude of different figures of the same name.

96. These primitive forms, though they are the figures of the smallest possible crystals, do not always represent the most minute particles into which the substance of the crystals may be reduced; for, if a hexahedral prism be divided by slices parallel to only three of its alternate sides, it will be reduced to a triangular prism, Fig. 53, and some primitive parallelopipedons can be divided diagonally, or from corner to corner, and then these forms also are converted into triangular prisms. In this way the particles of every kind of matter upon which the experiment has yet been tried have been reduced to the three simplest classes of solid forms: 1. The tetrahedron or trilateral pyramid, with four sides; 2. The triangular prism, with five sides; and 3. The parallelopiped, with six sides. These, then, are considered the forms of the most minute particles into which the various bodies in nature can be divided without separating those which are chemically compound into the different kinds of matter of which they are composed, and are therefore called *the forms of the integrant molecules of matter.*

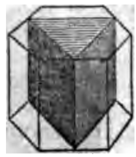

Fig. 53.

97. You should be careful not to confuse the idea of *an integrant molecule* with that of *an atom*. An integrant molecule may contain many atoms. Thus; blue vitriol is composed of sulphuric acid, and what is called an oxide of copper. But both these substances are also compounds; for, sulphuric acid consists of sulphur combined with a gas or air called oxygen, and the oxide of copper is composed of metallic copper and oxygen. Hence; even the integrant molecule of sulphate of copper must contain at least four atoms—two of oxygen,* one of sulphur and one of copper; and we cannot possibly divide this molecule without separating something essential to the very nature of the substance, or as chemists express it, decomposing the body. If deprived of either of these atoms, the molecule would not be sulphate of copper, but some other substance.

98. You perceive, then, that *crystallography*, as that science which treats of the structure of crystals is called, does not demonstrate the real figure of the atoms of matter, plausible as this supposition appears to the mere mineralogist.

* Chemistry teaches us that it contains several more.

It is most consistent with the present state of our knowledge to suppose that the atoms of matter are spherical; nor is it difficult to show how a few spheres may be piled upon each other so as to form the various figures of the integrant molecules. Place three ordinary playing-marbles on a table, ranging them in the form of a triangle, and cause them to adhere slightly together by using a little soft wax; then place another marble in the middle and upon the top of the others. This will give you an idea of the first form of molecule—the tetrahedron. Take off the topmost of these marbles, and the remaining three will represent the second form of molecule—the triangular prism:—and by placing on these, one or two additional layers arranged in the same manner, this figure will be made more distinct. Four marbles arranged in a square will display the rectangular parallelopiped; and upon this you can build up the cube, by adding another similar layer. If these four marbles be ranged in a lozenge, they form the rhomboidal parallelopiped; upon which you can erect the rhomb: or, if you choose to make the succeeding layers overlap the base and each other in any direction, the figure will assume the form of a parallelopiped oblique in every direction, so that none of its angles will be right angles. This you will best understand by actually trying the experiment.—Now, as all material substances that have been subjected to cleavage are found to be composed of some one of these three classes of molecules, all of which may be formed of spherical *atoms*, there is at present no known fact in nature to contradict the doctrine that atoms are spheres,—a doctrine that many philosophers adopt.

ATTRACTION AND REPULSION.

99. *Cohesive Attraction.*—It has been stated that all bodies have a disposition to approach each other by the attraction of gravitation. This tendency is often witnessed where it would scarcely be suspected by beginners in the study of nature. In calms upon the ocean, if two ships happen to lie near each other, their mutual attraction causes them to approach still nearer, and unless protected from collision by their crews, they may be dashed against each other after a few hours or days. The floating pieces of old wrecks are often found collected into groups by the action of the same cause. The molecules of bodies, both in the solid and liquid states, display attractions having some resemblance to the attraction of gravitation, though vastly more powerful

than could be inferred from the effects of gravity at sensible distances upon bodies of considerable size.

100. If a highly polished cambric needle be nicely balanced upon the tip of a finger, it may be so carefully lowered into a tumbler of water as to remain floating upon the surface: But as the needle is much heavier than water, it could not possibly float, were not the mutual attraction between the molecules of the fluid sufficiently strong to sustain the weight of the steel. Drops of water upon a very hot stove often gather themselves into small globules, and may be rolled about by the breath until they are evaporated slowly and without apparently boiling. These drops, when small, appear of a spherical shape; but when larger, they are very much flattened on the upper and under surface. Now, the form described evidently results from the attraction of the molecules of water for each other; for, if any number of particles mutually attract each other, they will struggle to approach until they become collected as closely as possible: that is to say; they will get as near to a common centre as their nature will permit them to do; and if they are all perfectly free to move, without being acted upon by other forces, they must assume the form of a sphere; because this is the only figure in which all parts of the circumference are equi-distant from a common centre. But every molecule of the water is also drawn towards the earth by its gravity; which opposes, to a certain extent the attraction between the molecules; and under the action of these two forces,—one tending to draw the water into a ball and the other to spread it out like a sheet, it assumes an intermediate figure, very much like an oblate spheroid (72). So strong is the mutual attraction of the molecules of the common soap-bubble, that it will bounce repeatedly like a playing-ball from the sleeve of a cloth coat or a furred glove, before it breaks. Drops of quicksilver scattered over a flat table or plate of glass, form themselves nearly into spheres, leaving no trace upon the surface on which they rest, but do not really touch. If two of these globules be pushed very close to each other, they rush together and instantly form a single globule. Place a large globule upon the face of a smooth mirror laid flat upon a table; lay a pane of window-glass upon it, and pile weight after weight upon the glass. In this way you can press the globule flatter, but you cannot bring the window-pane down to the level of the mirror; because the molecular attraction of quicksilver is strong enough to bear up any weight that can be safely used upon such materials.

101. These facts are quite sufficient to prove that molecular attraction really exists; but while gravitation takes place between bodies however distant from each other,—for it displays itself even between the sun and the planets,—the attraction that binds together the molecules of bodies is never perceived at sensible distances: for this reason, most philosophers regard it as a different kind of attraction from that of gravitation, and they have given it a peculiar name —*the attraction of cohesion.*

102. Cohesion holds together the molecules of any simple body; but in many cases, the surfaces of two separate bodies, composed either of the same or of different kinds of matter, are held together in a very similar way, though generally with much less force. Take two leaden rifle or musket-balls, and scrape or cut a clean smooth plane upon some part of the surface of each ball: press these planes strongly together with a slight twisting motion, and the two balls will stick together so strongly that a considerable effort may be necessary to separate them, though that effort will be slight in comparison with the force required to tear asunder a single piece of lead cast in the shape of the two bullets thus united. The "silvering," on the back of a looking-glass cannot be removed from the surface of the glass without hard rubbing, and far greater force is required to detach the gold from a piece of gilded wire; although, in these cases, the coatings are applied simply by means of powerful pressure. Two pieces of highly polished glass, when pressed together with great force, will sometimes break on the attempt to separate them: two pieces of smooth and freshly cut india rubber may be united almost as perfectly as if they had been, originally, only a single piece, by much more moderate force. These are examples of what is termed *adhesion.* It may exist either between similar or dissimilar substances. But between different substances, it is often found impossible to produce adhesion under most circumstances; as, between water and hot iron, mercury and glass, &c. This latter fact depends upon laws which you are not prepared to understand unless acquainted with the science of chemistry, and it is introduced here for the mere purpose of proving that cohesion and adhesion are not necessarily dependent upon the same causes in all cases.

103. The adhesion of solids for fluids is beautifully shown by suspending a window-pane upon four threads gathered in a knot, as represented in Fig. 54; four threads being attached to the glass by means of drops of sealing-wax.

When this pane is lowered horizontally until it comes in contact with the water in a basin, it will be found that considerable force is requisite to raise it from the fluid surface; and when so raised, a portion of the water will be found still adhering to the under surface of the glass, although the weight of this water will not at all account for the resistance offered against the separation. These facts distinctly prove that the cohesion of the particles of water to each other is very considerable, but that the adhesion of water to glass is still stronger.

Fig. 54.

104. *Capillary attraction.*—If the inside of a tumbler be moistened and then nearly filled with water, the liquid will be found to rise up at the edges, into the form of a beautiful curve, leaving the rest of the surface slightly hollowed out. Here it is evident that the glass attracts the water for a certain distance, and as the molecules nearest to the glass are thus elevated, those at a still greater distance must follow them to a certain extent, in consequence of the attraction of cohesion which binds them to each other. Balanced between the attraction of the glass with the cohesion of its own molecules on the one hand tending to raise it up, and its weight or gravity on the other tending to drag it down, the water assumes the curvilinear form.

105. It is not necessary that the glass should be round, in order to render this variety of attraction obvious; for, on dipping a flat pane of window-glass, previously moistened, into a basin or bucket of water, you will observe that the fluid rises into a similar curve on each side of the pane. Procure two panes of glass, moisten them, and bring them together in the position represented in Fig. 55, with two of their edges in contact, the two

Fig. 55.

opposite edges slightly parted, and the lower part of both panes plunged into a vessel of water. The water in this experiment, will rise highest between the panes where they are nearest together; assuming the curvature represented in the figure from A to B. To vary this experiment, choose a set of glass tubes of different diameters, Fig. 56, moisten them and plunge them into a basin of water. The fluid will rise in all the tubes above the surface in the basin, but it will rise in each to a height inversely proportional to the diameter of the tubes.

Fig. 56.

106. The effects of this kind of attraction were first observed and are still most remarkable in very fine tubes, with cavities as small as hairs; and hence it has received the name of *capillary attraction* from the Latin word *capilla*, a hair.

107. Capillary attraction prevails between all fluids and any solids to which they are disposed to adhere. If a glass be very dry or dusty, the cohesive attraction of the molecules of water may be stronger than their disposition to adhere to the glass; and in that case, the fluid near the glass will sink below the general surface, and instead of an upward curvature, as in Fig. 55, we shall perceive a downward curvature towards the glass; the neighbouring water endeavouring to assume the spherical shape. This is often beautifully displayed when a glass vessel is filled above the brim, at the moment before it overflows. The water is then piled up above the edge; but the moment a finger is brought into contact with the fluid very near the edge, the greater tendency to adhesion between the human skin and the water draws it across and moistens the edge of the glass; thus establishing the capillary attraction between the brim and the finger. This attraction continues without the aid of the finger when the glass is once moistened; and the water will continue to overflow until the surface sinks as much below the level of the vessel as it previously rose above it; the convex surface becoming concave. The same principle explains the floating of a needle upon water and the globules formed upon a hot stove (100), the power of spiders and other insects to walk on

water, &c. You will always observe, in the case of the needle and the insect, that the fluid around the bodies pressing upon the surface rises into a convexity on all sides, leaving the pressure in the middle of the hollow; and you will learn hereafter that the whole bulk of the cavity is always sufficient to contain water enough, if filled, to equal the floating body in weight. A spider on the water, standing on his eight legs, is really sailing in eight little boats formed by the cohesion of the water; and if his weight exceeded by the merest trifle, the buoyancy of the largest boats that this cohesion can build, he would instantly sink. Mercury has a much stronger cohesive attraction, and is much less prone to adhere to glass; and the effect on the surface produced by the immersion of a glass capillary tube sunk into mercury contained in a glass vessel is clearly displayed in Fig. 57, where the fluid in the tube stands far below the level. These facts are sufficient to show the close connexion generally existing between cohesion and adhesion.

Fig. 57.

108. As the power of capillary tubes increases inversely as their diameter, it becomes very great when the tubes are very small. The following are familiar examples of the agency of this power. The larger passages in a piece of sponge thrown into a shallow dish of water elevate the fluid but a short distance; but the finer passages convey it to a very considerable height. The intervals between the particles of loaf sugar carry dampness into the mass to a height proportioned to the closeness of the grain of the loaf. A lamp-wick, properly dressed, supplies sufficient oil to the flame from a depth of several inches; but if it be twisted too tight, though it may carry oil from a greater depth, it cannot yield a sufficient supply, owing to the smallness of the passages; while, if its texture be too loose it fails to raise the oil sufficiently. A piece of thread placed with one end in a vessel of water of moderate depth, and the other allowed to hang down below the vessel on the outside, will carry the water over the edge by capillary attraction, and will then empty the vessel by drops: In this manner a damp bandage may be made to carry cold water constantly to the lips or inflamed limb of a patient lying ill in bed, from a vessel upon a table by the bed-side. The sand upon a beach is always kept wet by capillary attraction, for some distance above the tide—giving life to multitudes of minute marine animals which would be exterminated by enemies were they to venture into the free element.

109. The height of a fluid in irregular capillary tubes is etermined by the diameter of parts of the tubes in which e fluid finds its level, and not by their size between that oot and the general surface of the fluid in the reservoir. hus, in all the little vessels represented in Fig. 58, various s is the form of the parts which touch the surface of the uid in the reservoir, this fluid will rise to the same height, ecause the little tubes are all of the same diameter at their pper part. But, of course, in the vessels A and B, if the ower portions were too wide to draw the fluid completely up to the commencement of the narrower part, the height would be determined by the diameter of the wider portions.

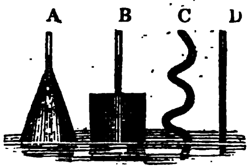

Fig. 58.


Fig. 59.

If the end of a funnel with an extremely narrow orifice be made to touch water, it will become filled to a certain extent; as represented in Fig. 59; and the height will be the same as if the end of the funnel were a tube as wide throughout as the fluid at the surface: but if the orifice be very fine, so that a long tube of the same diameter would attract into it a column of the whole height of the funnel, this vessel may be entirely filled when the orifice is removed from the reservoir and is held freely in the air. For the same reason, when a very small orifice is made in the bottom of a bucket the water will not escape, even if the bucket be filled.

110. Capillary attraction plays an important part in the living economy of plants and animals. The extremely delicate tubes or cavities, called vessels, in the substance of a tree, have much to do with taking up from the ground the moisture and other nourishment of the plant. The food of animals is reduced to a fluid state by digestion, and the organs of digestion have their surfaces covered by incalculable multitudes of little vessels, more delicate than the pile of velvet. Whether these vessels actually open upon the surface or not is still a disputed question, but that the digested fluids do actually enter them is well known, and though it is by no means certain that capillary attraction is the only cause of this taking up of the food, there

can be no doubt that it powerfully aids in the process. If the larger end of one of these vessels, with several branches of different sizes, were placed in contact with water; as in Fig. 60; the fluid would rise in each branch to about the height represented by the shading. When once admitted into these tubes, the fluids produced by digestion are made to circulate by other arrangements, the study of which is not considered as belonging to natural philosophy.

Fig. 60.

111. Capillary attraction may produce singular motions in bodies floating upon the surface of fluids. Fig. 61 represents a section of a vessel of water, upon the surface of which float three pieces of cork, A, B and C. The surface of the fluid is changed from its level into several curves by the attraction of the sides of the vessel and the pieces of cork. A and B being near together, act like the two panes of glass in Fig. 55, and cause the water to rise higher between these corks than it does between either of them and the sides of the vessel.

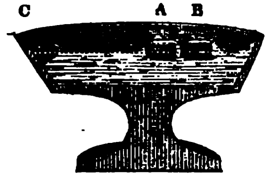

Fig. 61.

112. These corks, being moveable, and compelled to support the weight of the water thus elevated between them, are brought together by the reaction of this weight much more forcibly than they would be by their mere gravitation towards each other. For the same reason, a cork or a group of corks thus floating in a vessel, will be gradually drawn towards the nearest part of its margin, with constantly increasing speed, until they rush or are lifted up the curve where the water rises against the side, and will take the position represented at C, in the figure. This is the reason why motes floating in a tumbler are soon collected around the edge of the water instead of being equally spread over its surface.

113. Whether cohesion, adhesion, and capillary attraction are produced by some one general cause, and whether that cause is analogous to gravitation, are questions upon which philosophers are still undecided; but their similarity in many respects renders it by no means improbable that, at some future time, they may be proved to be identical.

POROSITY OF BODIES.

114. *Porosity of bodies — Molecular repulsion.* — The molecules of bodies are not in contact with each other, however dense and hard the bodies may be; for, the particles may always be made to approach each other by simple cooling. Cold contracts, and heat expands all bodies, with two or three apparent exceptions. Thus; let an iron bar be exactly fitted to a metallic ring, when they are both at the usual temperature. If the bar alone be heated in the fire, it will become visibly enlarged, and will no longer enter the ring. If it be then cooled in ice, it becomes contracted and will no longer fill the ring. If the ring be heated instead of the bar, it will hang loosely upon the bar; but if cooled in ice it contracts and refuses to admit the bar. Yet, in these and all similar cases, the weight of the bodies remains unchanged. From these facts, it evidently follows that the molecules and, probably, the atoms of bodies are never in contact, but are kept asunder by heat; which seems to cause a repulsion between them, overcoming, to a certain extent, their attraction of cohesion. Their distance from each other is, therefore, regulated by the balance between these contending forces. We know no limit to the degrees of heat and cold, or to the expansion or contraction of bodies under their influence. We may therefore conclude that there are always intervals between the particles of matter; or, that *porosity is a property of all substances.* Let us illustrate this fact.

115. Cork, when long immersed in water, imbibes it like a sponge. Wood does so likewise, and sinks at last by its increased weight: thus wrecks often finally disappear. The butt of a hard, green hickory log shows you visible passages for the sap. Chemical substances can be forced into every part of the heaviest timber, so as to preserve it from decay. Meat is thoroughly salted almost immediately by tying it up in a close bag of pickle, and sinking the sack with a rope attached to it, deep into the ocean; the great weight of the water forcing the fluid into every pore, without bursting the bag. By the Bramah press, water may be forced through the pores of iron or even gold.

116. Sugar, salt, and many other substances are *dissolved* when thrown into water: their molecules are separated and diffused through the fluid; yet in general, the solid substance and the fluid, taken together, occupy less space after than before the solution; proving that the dissolved particles must enter the pores of the fluid as sand or sawdust enters a box *full* of grapes.

117. It is obvious, then, that *bodies* are not impenetrable, though matter is so. It is only the *atom* that is impenetrable, because it is only the atom that is *matter*; and bodies contain both *atoms* and *spaces*. Even the *molecules* are not impenetrable: thus, when vitriol is poured upon chalk,—every molecule of which is composed of at least two kinds of matter, carbonic acid and lime,—the vitriol penetrates and divides the molecules of chalk, seizing upon that part of them which is composed of lime, to form with it *new molecules*, while those parts which are composed of carbonic acid become independent simpler molecules, which repel each other, and fly away in the form of gas or air. Heat alone, often thus *decomposes* compound molecules; as when gunpowder is fired; and had we instruments sufficiently hard and sharp, we might decompose them by division; but nothing can decompose an atom. When you drive a nail into wood, thrust your hand into water, or wave a sword through the air, you do not really penetrate these substances. You only separate their molecules and penetrate the spaces between them.

118. Philosophers generally attribute the repulsion of molecules or atoms, not to the atoms themselves, but to what is commonly called *heat*, which they regard as a kind of matter too light to be weighed and too thin to be seen, that is combined in different quantities with all other matter; its particles repelling instead of attracting each other, and thus constantly tending to force asunder the particles of other bodies to which they adhere, until the mutual attraction of the latter particles balances the repulsion of the heat. As this supposed agent, *heat*, is interested in all subjects and experiments connected with natural philosophy, our language in relation to it must be made clear to the student.

119. The word *heat* is commonly applied without distinction to the peculiar *sensation* produced by touching a hot body, and to *the cause* of that sensation. Philosophers, whose language requires great accuracy, adopt a different term to signify *the cause* of the phenomena vulgarly attributed to heat. They call it *caloric*.

120. Some theorists, indeed, consider all the phenomena usually attributed to caloric as so many results of a peculiar kind of motion among the particles of matter; but the other hypothesis, (118) though it admits not of positive proof, is much more convenient for beginners, and it is therefore adopted in this little work.

121. Caloric can no more be collected into a tangible body

than can the light of the stars; and we could weigh the beams of the sun as readily as the warmth of the fire: but, seeing the one and feeling the other, it is difficult not to believe that both light and caloric are composed of matter. Because they can not be *weighed* by any known means, these and some other agents are called *imponderables*, and the matter of which we suppose them to be formed, *imponderable matter*. In many of their properties these imponderables so resemble each other that some theorists suspect them of being only varied effects of the same general cause. At present, however, we must regard them as distinct natural agents, although we may sometimes employ the phenomena of one such agent to illustrate the properties of another.

122. If an opaque body be placed between the sun and any material substance, it casts a deep shade, and is said to "stop the light." If the body be a mirror, much of the light which is thus stopped obviously rebounds like a playing-ball from the surface, and appears to emanate from the mirror itself; being *turned back* or *reflected* therefrom.

123. But reflected light is always weaker than that which comes directly from a luminous body: showing that a portion of light disappears at each reflection. Again; if you try the last mentioned experiment with a rough, dark body in place of the mirror, the shadow is as deep as before, but you find that scarce any light is reflected. What becomes of the light that disappears in these cases? This question may be plausibly answered by means of facts drawn from the history of light; but, as the phenomena of light and caloric are similar in such cases, it is most convenient to illustrate them by analogy from the history of the latter agent.

124. While holding one end of a rod of glass, five or six inches in length, you may heat the other extremity to redness in the flame of a large lamp, yet your hand still receives no impression from the heat. But should you try a similar experiment with a piece of iron wire, you would be compelled to drop the hot metal in a few moments. These facts may be explained by supposing that caloric is conducted from molecule to molecule with great facility along the metallic wire, but with difficulty along the glass. The metals are said to be good *conductors* of caloric, and glass is said to be a bad *conductor*.

125. But caloric may be transferred from one body to another much more rapidly. It shoots out in all directions from a heated body, like light from a candle. Bring your

hand within a few inches of a redhot bar from the forge, and the heat will be instantaneously intolerable. This rapid mode of travelling is called *radiation*, and radiating caloric is capable of being reflected or made to disappear in the same manner with light, under the circumstances already noticed. We may therefore infer what becomes of the light in the cases mentioned in paragraph 123, by ascertaining what becomes of the caloric under similar circumstances.

126. If a polished body which is a bad conductor of heat be placed between an observer and a hot stove, the caloric radiating from the stove will be arrested by the body, at least for a time—the observer will be "*shaded from the heat.*" Let him then place himself in front of the body, and he will find the caloric thrown strongly back upon his person, as though the body were itself nearly as hot as the stove. Yet the quantity of caloric thus reflected is not equal to that radiated from the stove to the reflecting body. On feeling the latter it is found to become warmer as the experiment is continued. If the body be a good conductor of heat, much less caloric is reflected by it, and it becomes rapidly hotter. If its surface be rough, the quantity of reflection is still further diminished, and the body itself becomes so hot that it radiates caloric from its own surface nearly as fast as it is received from the stove, and can no longer "shade the observer from the heat."

127. No known substance reflects all the heat or all the light that falls upon it; and hence if these imponderables be really *material*, there must be an attraction between their molecules and those of all other bodies, causing a portion of them to be *absorbed* into the interior of these bodies by attraction. This form of attraction, then, is one of the properties of light and heat, and probably of all other imponderable matter.

128. If a candle and a heated ball be placed in open space, both the caloric or the light diffuse themselves by radiation in every direction. Let A, Fig. 62, represent a candle, and B, C, D, E, four parallel boards set upright upon a table, ranged at the distances of one, two, three and four feet from the light respectively, and let a hole of one inch square be cut in the middle of the first board, as represented in the figure. In this experiment, the light spreads equally in every direction from the candle, and that portion of it which falls upon the hole passes onward until arrested by the board C. But C is removed to twice the distance of B,

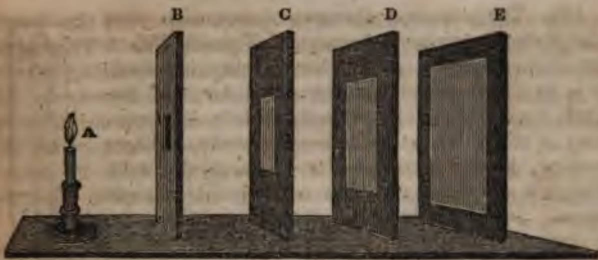

Fig. 62.

and consequently, the part illuminated upon the surface of C is twice as long and twice as broad as the hole in B: that is, it measures four square inches. Take away the board C, and the light will pass on to D, which being at three times the distance of B, the surface illuminated upon this board will be three times as wide and three times as long as the hole, and will measure nine square inches. Take away the board D, and, for the same reason, sixteen square inches of surface will be illuminated on the board E. It follows, then, that when light radiates from any centre, the space which it illuminates at different distances varies *directly* as the square of these distances (Note, p. 37). But the strength or *intensity* of the light becomes less in proportion to the space over which it is spread: therefore this intensity varies *inversely* as the square of the distance. Repeat the same experiment with a heated ball, in place of the candle, and it will be found that the caloric radiates and becomes weakened by distance, in precisely the same manner.

129. According to the doctrine that the imponderables are fluids, their particles have a strong repulsion for each other, and dart out into free space, from bodies discharging them, in straight lines, and in every direction, like radii from the centre toward the circumference of a sphere.

130. In the preceding paragraphs, we have chiefly considered caloric in only one of its states or conditions—that in which it is free to fly off by radiation, or to be conveyed from particle to particle along conducting bodies. In this state it is called *free* or *sensible caloric*, and when it comes into contact with a living being, it produces the sensation of heat. But caloric exists in bodies in a condition in which it cannot affect the senses: but this will be better understood after an explanation of the construction of the *thermometer* or *heat-measurer*.

131. The common thermometer consists of a glass tube containing mercury, A, Fig. 63. When the thermometer is made, the mercury is boiled, so as to drive out all moisture and air, and the small end of the tube is sealed while the mercury is still hot, so as to fill it completely. When cooling, it contracts, and the part of the tube which is not filled contains nothing: it is a *vacuum*. In this instrument, the slightest increase of temperature expands the mercury, causing it to rise in the tube, while the slightest cooling contracts it and causes it to fall. A scale is adapted to the tube, and by the height of the mercury within, as measured by this scale, we can determine very exactly the temperature at any moment.

Fig. 63.

132. Place a metallic vessel upon a stove, warm enough to keep a kettle boiling. Nearly fill this cup with cold water, and, put into it the bulb of a common thermometer. The mercury in this thermometer will continue to rise, until it reaches the 212th degree of the scale, when the water will begin to boil. This clearly shows that caloric is constantly conducted by the vessel from the stove to the water; and this stream of caloric must continue to flow into the water after as well as before it begins to boil. Hence, you would infer that the water must continue to grow hotter: but this is not the case. From the moment that boiling commences, the mercury remains unmoved at 212 degrees, until the water is entirely "boiled away." But as this requires a great deal more time than is occupied in raising the temperature to the boiling point, it is plain that a great quantity of caloric must enter the water, during the process of boiling, without influencing the temperature. What becomes of this caloric?

133. You will probably answer that it is carried off by the steam. But the steam is already heated to 212 degrees when first formed from the water: if then it carries off with it all the heat that continues to stream into the vessel from the stove in the foregoing experiment, it must carry off much more than 212 degrees of caloric, and we should expect to find it much hotter than the water. Yet if you loosely cover a vessel of boiling water and insert the bulb of a thermometer through the cover, the mercury will stand at the same height of 212 degrees whether the bulb be sur-

unded by the steam or plunged into the water. What, ien, becomes of the surplus caloric carried off by the steam? is easy to prove that this caloric is conveyed away by the eam, in a condition which renders it incapable of affecting ie senses,—in a condition in which it is called *latent* or *isensible* by many philosophers.

134. When steam is cooled to a point below 212 degrees, is once more converted into water. Hold any cold body a the steam issuing from a kettle of boiling water, and you vill find that it instantly becomes wet, being covered by lrops of condensed steam: but, at the same time, the body becomes hotter very rapidly, although the water deposited upon it preserves nearly or exactly the same temperature of 212 degrees. Whence does this body derive its increased temperature? certainly, it must be from the steam, although this latter has lost little or no sensible or free caloric. Steam in cooling, then, must give out a quantity of caloric in the free state, which previously existed within it in an insensible or latent state. Whence did it procure this latent heat? Assuredly from the fire or stove while the water was boiling without growing hotter (132). Here, then, you find the reason why steam remains at the same temperature with the water from which it is formed, though carrying off with it a continually increasing amount of caloric. It renders the caloric *latent.*

135. Let A, Fig. 64, represent a glass vessel, called a *retort,* containing a pound of water, communicating by means of a bent tube with the bottom of another glass vessel, B, called a *receiver,* in which there are four pounds of water. Suppose that the water in the retort is made to boil by means of a lamp, as represented in the figure. The steam renders latent all the heat received from the lamp, and passing through the tube into the cold water in the receiver, it becomes itself condensed into water, giving out this latent heat in a free form to the whole contents of the receiver. Now, it is found that, when the whole of the water in the retort has been boiled away, there remain five pounds of water in the receiver, at a temperature of very nearly 212 degrees; as shown by the thermometer C, attached to the apparatus. To boil away a given quantity of water at the ordinary temperature therefore requires an amount of caloric at least as great as that which would raise five times the quantity to the boiling point; and three-fourths at least, of the excess of caloric in steam over that of boiling water is latent and insensible—ready to re-appear

Fig. 64.

and be made useful whenever and wherever the steam may be condensed. Thus; by means of a boiler and tubes, steam is conveyed to all parts of large buildings, being continually condensed and giving out its latent heat to the tubes, which radiate it in all directions to warm the inmates, while the hot water thus formed trickles back into reservoirs and is returned to the boiler ready to be re-converted into steam. In this way the "heat" *so called*, of a fire is carried off by steam, to cook provisions, warm baths or cauldrons, and answers a thousand useful purposes where the fire itself cannot be carried.

136. Now, suppose that, instead of heating the water in the metallic vessel (132) you place it in a situation colder than the freezing point of water: the thermometer will then gradually fall to that point, which is at 32 dgreees of the common scale. The water will then begin to freeze; but although caloric is continually radiating from it into the colder atmosphere, the mercury will fall no lower until all the water is frozen; because water contains a great deal more caloric in the latent state than ice, and, in freezing it gives this out in the form of free caloric, keeping the water and the ice at the same temperature till the former is all congealed. If we reverse this experiment by plunging the thermometer in a cup full of powdered ice placed on a hot stove, the mercury will remain at the height of 32 degrees till the ice is all melted.

137. What we have said in relation to water is equally true of all other ponderable matter. There is no known substance so solid that it may not be melted by heat, and there are very few that have not been melted by art. In

he same manner, a continued increase of temperature would at last convert any liquid into an air or gas. By art we can readily boil away even some of the metals, and in the craters of volcanoes far more unyielding substances are found to be converted into vapour. On the other hand, we know very few liquids that cannot be rendered solid or frozen by art. Recently, one of the most permanent airs or gases—that which escapes from champaigne wine, cider, beer, &c.—has been converted into a solid mass, so as to be handled and broken in pieces.

138. Whenever any substance passes from the *solid* to the *liquid* or from the *liquid* to the *aeriform or gaseous* state, caloric is absorbed and rendered latent or insensible; and whenever a substance passes from the aeriform to the liquid, or from the liquid to the solid state, caloric is rendered free and sensible.

139. It is safe then to conclude first, that all ponderable matter may exist in either of three states; the *solid*, the *liquid*, and the *gaseous* or *vapoury*; second, that the actual state in which the body may be found depends upon the quantity of caloric, and chiefly of latent caloric that it contains. If the temperature of the earth were to be raised to a sufficient degree, the most solid portions of the globe would first be melted and then boiled away until nothing remained but one vast mass of gas or vapour, through which the stars of night would shine clear and scarcely dimmed, as they now do through the tail and sometimes through the body of a comet. If, on the contrary, no more caloric were received by the earth from the sun or any other source, it would become gradually cooled by the radiation of its heat into the unbounded space around it, until all the liquids and even the gases, including the atmosphere or air which we breathe, would be congealed—frozen—contracted—and this vast globe would shrivel into a little ball, probably much smaller than the smallest of the planets that the astronomer brings into view by the aid of powerful telescopes. Nor would such changes require either a very great or a very wonderful display of Almighty power.

140. There is one effect of the change of the quantity of latent heat when bodies pass from the liquid to the solid state, or the reverse, that ought not to be passed over. You have been told already that there were one or two apparent exceptions to the law that heat expands bodies and cold allows them to contract. The most important of these exceptions is presented in the history of water and ice. If

water be taken at the boiling point—212 degrees—and be gradually cooled down to the freezing point—32 degrees—it will be found to contract according to the custom of other bodies, until it arrives at about 42 degrees of temperature; but after reaching this point, it begins to expand again, and continues to do so until it arrives at the freezing point. Again, in the act of freezing, water expands with violence sufficient to split the most solid rocks or burst a cannon. After the ice has once been completely formed it again becomes subject to the general law; for it will contract with cold and expand again with heat. Some pupils will be startled with the idea of cooling ice, but this is easily done, for even the air in the winter is so cold that the mercury in the thermometer will fall very far below 32 degrees. Let us suppose that on some evening after a spell of warm weather, the air suddenly falls to 0, or what is called *the zero* of the common scale, and that during the night a large pond of water is frozen over. Of course the ice will be reduced to zero in temperature, and will be contracted to a corresponding extent. Now, if on the succeeding day the mercury should rise to 32 degrees, the ice will expand so much that it becomes too large for the pond, and will be pushed up to some distance all round the shores, perhaps ploughing the mud or moving the pebbles as its edges are forced upon the land. But if the pond has been frozen when the mercury stood at about the freezing point, and during the succeeding night the mercury has suddenly sunk to zero, the old ice will contract with the cold until it no longer covers the pond, and next morning you will find an entire margin of new ice surrounding all the shores like a ribbon.

141. We are unable to explain either the changes in the density of water between the temperatures of 32 and 42 degrees, or the expansion of ice in the act of freezing. That both these phenomena are caused by a singular modification of arrangement among the molecules is obvious; but this exception to a general rule does not destroy the rule; for, it is found that, generally, even ice and water themselves are subject to the rule. We must be contented at present to receive the fact without reasoning on the cause, while we admire the beneficence of Providence in making the exception. Had it not been made, the greater part of the temperate portions of the earth would be uninhabitable by man—spring and autumn would scarcely exist—and we should be hurried from the extreme of winter to that of summer and the reverse, almost upon the instant. But let us explain. After

the autumnal equinox, the sun apparently travels southward, and shines more and more obliquely upon the northern half of the world. The earth then radiates more caloric during the night than it receives during the day, which becomes continually shorter. As the earth is cooled on the approach of winter, the surface of the heated waters of lakes, rivers, and the ocean give out a portion of their warmth to the air, and thus render the climate much more moderate. As the water becomes more dense by cooling,the particles sink, and the warmer liquid from below rises to give off its heat and sink in its turn. But the quantity of sensible heat given off by this process is small; and if this circulation of particles were continued, the whole depth of the ocean, and the rivers and lakes would soon be reduced to 32 degrees—the freezing point—at which temperature nearly all their inhabitants would cease to live. The surface of the water would then begin to freeze, and, giving out its large supplies of latent caloric, would act as it now does, in rendering the climate milder and preventing a polar frost in temperate countries,at least during a few years. But the ice, were it not for its expansion in freezing, would be denser than the water, and would sink to the bottom as soon as formed; the sun returned northward in the spring would then find no floating ice to be melted by its rays, and thus to absorb its increasing heat by converting it into latent and insensible caloric. Thus then the weather would become rapidly warmer, evaporation would take place to a far greater extent, and the climate would be rendered hot and damp. Meanwhile the cooler water from the depths could not rise up to absorb any part of the heat, nor could the ice beneath it be melted; for water, though it readily conveys heat by the *circulation* of its particles in the manner above described, is one of the very worst conductors of caloric when its particles are at rest; and the particles of the upper portion of the water being warmer, and therefore lighter, could never descend as they now do, the moment that the water is cooled to 48 degrees. Each succeeding winter, then, would add to the quantity of ice in the depths of the sea and great lakes until the broad expanse of ocean in our latitudes would become one great glacier of solid ice, its animals would die, and the chief effect of the summer sun would be to melt—heat—evaporate—almost to boil the surface for a time, while its warmth would penetrate but a few feet in depth. Thus; a sweltering midsummer day would probably succeed a night of cold and mist. When the sun began to retreat once more to the southward, the cli-

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mate of Pennsylvania would be far more terrible than that of Palmer's Land or Nova Zembla. But now, when the heat of summer declines and the waters are reduced to the temperature of 48 degrees, all additional degrees of cold serve only to expand the liquid at the surface and cause it to float like a blanket over the fish and other aquatic animals, preserving them against any greater severity of the climate. Soon after this, the waters of the surface are reduced to the freezing point; the ice, in forming, liberates immense quantities of the caloric previously latent in the water, and, by expanding in freezing, continues to float; thus remaining always in readiness to moderate the heat of the approaching sun in the spring —often melting during the day to prevent oppressive warmth, and freezing again at night to prevent oppressive cold. To this property of water, added to the effect of the alternate evaporation and condensation of the same fluid, we owe the beautiful succession of the seasons.

142. *The three general states or conditions of matter; the solid, liquid and aeriform.*—In the present state of our knowledge it would be wrong to assert that the positions of the molecules of bodies are determined exclusively by the balance between the repulsive power of caloric and the attraction of gravitation or cohesion. These contending forces do not clearly account for the regularity of the arrangement of molecules observed in crystals, and the changes of arrangement among the atoms of compound substances that seem to convert one kind of matter into another; as in the case of the explosion of gunpowder. These latter changes are attributed to other forces, called *elective attraction* and *chemical affinity*, the consideration of which belongs to the science of chemistry. But, so long as the molecules of any substance continue unchanged in nature, the various general states or conditions of matter except the crystalline state may be very well explained by the balance above mentioned.

143. *The solid state.*—When the cohesive attraction of the molecules of a body is so much stronger than the repulsive force of its latent and sensible caloric that the molecules cannot be moved upon each other without difficulty, the body is said to be in *the solid state*, or, in ordinary language, it is called *a solid*:—as, ice, clay, charcoal, &c.

144. When a body contains so much caloric that the repulsive force of this agent separates the molecules far enough to allow them to move very freely among themselves, without mutual interference, the body is said to be in

the fluid state—or, it is termed simply *a fluid;* as, water, air, wine, steam, &c.

145. *The liquid state.*—When the repulsive power of the caloric does not entirely overcome the attraction of cohesion in a fluid, but allows the body to gather itself into drops or globules by capillary attraction; as in the case of water and mercury; the fluid is said to be in *the liquid state*—or it is simply called *a liquid.*

146. *The aeriform state.*—When the quantity of caloric in a fluid becomes so great that the cohesive attraction is entirely overcome and the particles appear to repel each other, like those of caloric itself, so that they would expand or separate to an indefinite distance if not held within limits by some force exterior to the body, the fluid is said to be in *the aeriform state*—or it is simply called *a vapour* or *gas;* as, steam, atmospheric air, &c. The term *gas* has been usually confined to those aeriform fluids which are not reduced to the liquid or solid state by ordinary degrees of cold, and the term *vapour* is applied to those which assume one or both these last conditions on becoming chilled. Common air is an example of the former class, and steam of the latter; but this distinction is purely artificial.

147. *Peculiar states or conditions of matter.*—There are several other important varieties in the state or condition of bodies, besides the solid, liquid and aeriform states, giving rise to peculiar properties very observable in certain bodies, though but partially, if at all, displayed in others. These properties also appear to result, at least in a great degree, from the balance between the repulsive and the attractive forces, modified, perhaps, by the shape and the arrangement of the molecules.

148. *Hardness.*—When the cohesion of the molecules is so firm that considerable force is required to cause them to move one upon another, the body is said to be *hard.* The atoms of all bodies are probably perfectly hard, because, being indivisible, they cannot be torn to pieces, and we have no reason to believe that they can be pressed or squeezed out of their regular shape by any force whatever:—but there exists no *body* that is perfectly hard; because all bodies may be indefinitely divided.

149. The property of *hardness,* which is found in greater or less degree in all solid bodies, does not appear to be at all dependent upon *density;* for, gold, silver and lead are far more dense than glass; yet cold glass will cut or scratch any of the metals with great ease. Flint has less density than

glass; yet the former will scratch the latter. Bodies generally become less hard when heated. Thus: cold iron very easily cuts hot glass. The diamond and sapphire are the hardest of all known substances.

150. *Tenacity.*—When the cohesion of the molecules is so strong that considerable force is necessary to pull them apart, the body is said to possess the property of *tenacity.* This may be tolerably well defined by the common word *toughness.* Tenacity does not depend upon hardness; for it is possessed even by liquids which permit their particles to move one upon another with great freedom. Molasses, though very soft, has considerable tenacity; melted glue has much more; nor is the property absent even in water, as is proved by the force required to lift a plate of glass from the surface of a basin (103). Steel is the most tenacious of all known bodies; for it will support the greatest weight without breaking. Many bodies are composed of collections of grains which do not cohere very strongly, yet each grain may be possessed of great hardness and great tenacity. Sand-stone scratches glass, and its grains have great tenacity, but they cohere so slightly in many specimens that the body itself may be crumbled to pieces between the thumb and finger—such bodies are said to be *friable.*

151. *Brittleness.*—A body may have both hardness and tenacity to any degree of perfection, and may yet be broken by bending. Indeed it is usually in the harder kinds of bodies that this property, which is called *brittleness,* is most clearly perceived. Glass and steel possess the properties of hardness, tenacity and brittleness, all in high perfection; horn and tortoise-shell are very tenacious and quite brittle, though they are not hard; while rosin, when quite cold, is neither hard nor very tenacious, but is extremely brittle. This property appears to depend upon some unknown peculiarity in the arrangement of the molecules; for, many of the metals, after being heated and suddenly cooled, become extremely brittle, but if allowed to cool very gradually, they lose this property more or less completely. By heating steel to a certain degree, and then slowly cooling it, we reduce its *temper;* thus rendering it softer and less brittle; while by sudden cooling the temper is raised. Similar changes are effected in glass, and the process is called *annealing.*

152. *Frangibility.*—The cohesion of molecules in many brittle bodies is so nicely balanced that the jar produced among them by breaking off a part of the body occasions it

to fly into many pieces. Such bodies are said to possess the property of *frangibility*, which is a modification of brittleness. A drop of melted glass, Fig. 65, very suddenly cooled by being allowed to fall into water, forms a toy known by the name of Prince Rupert's drop. If laid upon a clean table, the large bulb of this toy may be smartly struck with a smooth hammer without being broken; but if the extremity of the tail be broken by the finger nail, or if any part of the drop be scratched by a grain of sand, the toy actually explodes and falls into dust. This experiment is dangerous to the eyes, unless performed under cover. Glass tubes or bottles carelessly annealed frequently fall into several pieces, upon being slightly handled.

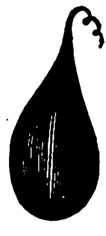

Fig. 65.

153. *Malleability.*—There are many bodies so hard that they seem to have no resemblance to a fluid, yet by hammering or very great pressure their shape may be changed at pleasure, and they may often be rendered considerably smaller, or more dense. In other words, their molecules may be moved upon each other by great forces and may be even pressed considerably nearer together. This is the case with many metals, such as iron, copper, lead, gold, &c. By being passed between heavy rollers, these metals may be spread into thin sheets. This property of bodies is called *malleability*. Of course, when a malleable body is thus rendered more dense, part of the latent caloric which previously separated its molecules must be squeezed out, and being then radiated or conducted away, the repulsion is permanently lessened, and the particles do not return to their former distance. The caloric thus forced out becomes *sensible;* and a bar of iron may be made red hot, simply by hammering it. Many bodies that are brittle when cold, become malleable when warm; as glass, the resins, &c. Malleability is directly opposed to brittleness.

154. *Ductility.*—This is a property so similar to malleability that it may be considered as a modification of it. This property enables us to draw any kind of matter into wire or thread. Iron, hot glass, silver, &c., are very ductile, as are also molasses candy, and even fluid molasses. But the most malleable substances are not always the most ductile. The substances that permit their particles to be *driven* together with the greatest ease are not those which admit of being

stretched to the greatest extent. Thus; gold is the most malleable of metals, because it can be beaten or rolled into the thinnest plates; but it will not bear to be drawn into wire nearly so fine as that which can be made from platina;—the foil or leaf of lead or tin is made very thin, but the finest wire obtainable from these metals is quite coarse in comparison with that obtained from other metals.

155. *Elasticity.*—Many bodies which may be easily pressed or bent out of their existing shape, so as to change the relative positions of their particles, are observed to recover their former figures very rapidly when the force producing this effect is removed. The property upon which this recovery depends is called *elasticity.* Ivory, glass, india rubber, and all the gases, may be classed among the most elastic, and clay, putty, and most of the liquids among the least elastic substances. Inelastic bodies when thrown against a hard and fixed substance—a wall, for instance—do not rebound therefrom: if soft, like clay and putty, they become flattened, and usually adhere where they strike. If any perfectly hard body were in existence, it would necessarily be perfectly inelastic, for its particles could not be compressed by any amount of force; yet, in solids, highly elastic bodies are found among very hard substances.

156. When an elastic body is allowed to fall upon any hard substance, it rebounds, and the more perfect the elasticity, the higher will it bounce. An ivory ball, if allowed to fall upon a marble table, rebounds very nearly to the height from which it falls, and continues in motion for a long time.

157. When an elastic substance is compressed, a portion of its latent caloric is forced out and becomes sensible; but is rapidly re-absorbed if the compression is instantly removed. Before friction matches were invented, a very ingenious instrument was sometimes employed for lighting segars. A little metallic tube, closed at one extremity, A, Fig. 66, was provided with an air-tight piston, B, on the extremity of which a small piece of common spunk, C, was secured by being pressed into a small cavity in the metal. The piston, being inserted into the tube, was suddenly driven down with great force by the hand, and immediately

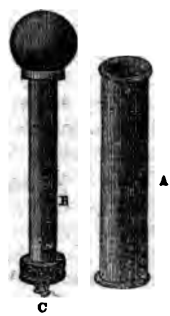

Fig. 66.

withdrawn. The great compression of the air in the tube, forced out sufficient heat to set on fire the spunk: yet after the piston was withdrawn, the air was no warmer than before, because it had become expanded by its elasticity and the free caloric forced from it immediately became again latent.

POLARITY.

158. *Magnetic Attraction and Repulsion.*—You know something of what is meant by the mariner's compass, by means of which mariners are able to find their way across the ocean. The *needle* of the mariner's compass is supported upon a pivot allowing free motion in all directions, and when unrestrained it always settles to rest in such a position as to point nearly north and south. Any body capable of displaying this property is called *a magnet.* The principal substances which display magnetic powers, are the metals iron, nickel and cobalt—the first in a very high degree, and the two last but feebly. Some minerals are magnets by nature. There is a peculiar ore of iron, called magnetic iron ore, which always displays the property; but most magnets are made such by artificial means.

159. Let a bar of soft iron, or an ordinary fire poker not made of very hard metal, be heated repeatedly, and suffered to lie horizontally for many days in succession, in the direction pointed out by the needle of the compass. After a certain length of time, this bar will be found to be slightly magnetic. Suspend it horizontally upon a long cord, at a considerable distance from any other body of iron or steel, and it will settle to rest in a northerly and southerly direction. The extremity which lay next the north while the magnet was being prepared, will always point in

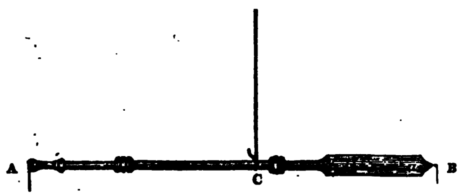

Fig. 67.

the same direction after it is suspended. Thus you have manufactured an artificial magnet, which will retain its power for a considerable time.

160. This bar having been thus suspended, as represented

at A C B, Fig. 67, let a piece of iron, not magnetized, be brought near the centre, C, in a direction perpendicular to that of the magnet. It will then be found that there is an attraction between the two pieces of iron, and the magnet will be swayed from its position, so as to render the cord C D, a little oblique; but this effect will be very slight. Let the unmagnetized iron be now brought nearer either extremity of the magnet, at A or B, and the attraction will be found much more powerful at these points; for the two pieces will approach each other rapidly until they come in contact, and will then adhere together with a force proportional to the strength of the magnet. If a fine cambric needle, or any minute piece of iron be presented to the middle of the magnet, little or no attraction will be perceived between them; but if presented to either extremity of the bar, at A or B, it will be instantly snatched up and will remain suspended as is represented in the figure.

161. The foregoing experiments prove that when a body is magnetic it has a strong and peculiar attraction for iron, and some other substances; but this attraction is not equally displayed in all parts of the body: on the contrary; it is concentrated chiefly in two opposite points; thus displaying very different properties from the various forms of attraction previously explained, which reside equally in every part of the attracting body. The two points at which the magnetic power is concentrated are called *poles*. That which points to the northward is usually called the *north* or *boreal pole*, and the opposite point is called the *south* or *austral pole* of the magnet. But it is not necessary that the magnetized bar should be straight—the same properties may be artificially given to bodies of any required form. Fig. 68 represents what is called a horse-shoe magnet, one of the most common and convenient instruments for experiments in magnetism. The letters N and S designate the north and south poles, so called, for want of more appropriate terms.

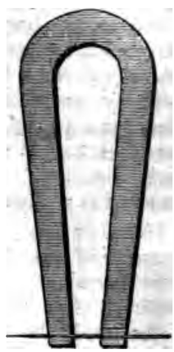

Fig. 68.

162. If we add other needles to the extremities of those represented in Fig. 67, the power of the magnet acts through those already adhering to the bar, and a second pair of needles will adhere to the first, a third pair to the second,

&c., until the weight of the series overcomes the force of attraction, and they fall: but the moment they are parted from the bar, they cease to adhere together. This shows that a magnet has the power of converting other pieces of iron into magnets as long as they are in contact with it; for, each of these needles acts as a distinct magnet, having its two poles, like the principal bar, until the series becomes detached. To express this fact in philosophical language, a magnet possesses the power of polarizing any piece of iron which is placed in close proximity to either of its poles. This power is beautifully displayed by casting a straight magnetized bar into the midst of iron filings, spread lightly over a salver or plate, and then gently agitating the plate. The particles of filings being repeatedly tossed from the surface by this means, are left free while falling to obey the attraction of the bar, and gradually range themselves into

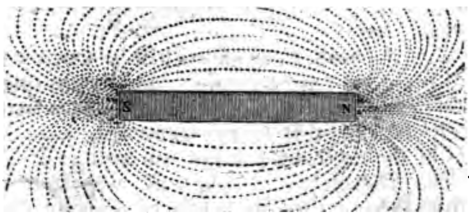

Fig. 69.

beautiful curves terminating in one or the other pole, or extending from the one to the other, as represented in Fig. 69. Each of these curves is composed of a row of filings, *polarized* like the needles in the former experiment.

163. If a needle be kept suspended for a long time from a magnetized bar, it will gradually acquire independent and more permanent magnetic power; so that its polarity will continue after it is removed from the source of attraction. If the needle be stretched across the extremities of a strong horse-shoe magnet, so that the head may be near the north pole and the point near the south pole, it will become magnetized more rapidly and strongly, and you will find, upon suspending it, that the extremity which has been near the north pole will point to the southward, while that which has been near the south pole will point to the northward. These are examples of what is termed magnetic induction.

164. When the north poles or the south poles of any two magnets are brought near together they repel each other

forcibly, but when the north pole of the one is placed near the south pole of the other, they spring together with energy. Carve for yourself an image of a swan of cork or light wood, Fig. 70; and having bored a small hole from the breast to near the tail of the bird, pass a piece of magnetized wire through the hole, placing the north pole next the breast, as at N, and secure it there with wax. Place this swan upon the surface of water in a basin. If you now present the north pole of a magnet to the beak of the swan, the bird will turn and move away, and on presenting the south pole, the swan will approach and follow the magnet. If you approach the tail instead of the beak, these effects will be exactly reversed.

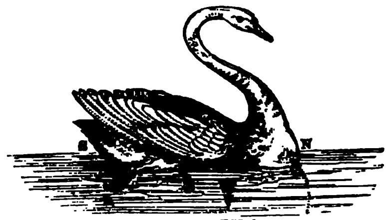

Fig. 70.

The earth is a great magnet, and for this reason one pole of the needle of the compass and all other magnets tends to the northward, and the other to the southward, these being the directions of the magnetic poles of the earth.

165. The phenomena of magnetic attraction differ so widely from those previously described as being properties of the bodies by which they are displayed, that like those of heat, they have been attributed to the agency of a peculiar imponderable fluid which has been called *the magnetic fluid.* There are also several other agents capable of giving polarity to bodies and to the molecules of bodies; so that the magnetic is by no means the only kind of polarity: but in whatever mode bodies or their particles may be polarized, one general law is observed in all such cases:—*Similar poles repel each other and opposite poles attract each other.* You must perceive at once how simply and beautifully this may explain the phenomena of crystallization, the brittleness of bodies very suddenly cooled, the frangibility of Prince Rupert's drop, &c. When the molecules of a body are dissolved in fluid or reduced to the liquid state by heat, they may take any position with the greatest ease. If, then, they possess polarity, the attraction of the opposite poles and the repulsion of the similar poles must cause them to arrange themselves in regular order, like magnetized iron filings. There is strong reason for the belief that in most kinds of matter

when passing from the liquid to the solid state the molecules become polarized. If the change be slow they have time to assume their proper positions, and are therefore enabled to construct those beautiful figures which are called crystals, varying in shape in different substances according to the forms of their molecules. But when the change is hurried the molecules are entangled and confused too quickly to admit of their systematic arrangement by polarity, and this confusion must have a great effect upon the cohesion of such bodies. With these remarks we may safely take leave of our elementary view of the general properties of matter and the special properties of bodies.

CHAPTER II.

MECHANICS.

OF MOTION AND FORCE.

166. *Momentum.*—We will now consider the conditions of bodies in motion and bodies at rest, with their inertia or the forces which they exert in resisting any change in these conditions. You have been instructed that nothing material is positively at rest. A gentleman in Quito, nearly under the equator, when seated in his elbow-chair, *at rest in relation to every thing around him*, is really moving around the centre of the Earth, at the rate of about 1000 miles per hour, and with the earth in its orbit around the sun, at the rate of 68,000 miles per hour. When we say that bodies are at rest, we mean only that they do not change their relative place among other bodies with which we may compare them: thus, a ship riding at anchor in a river is at rest in relation to the shores and bottom of the river, though she is absolutely in motion with the whole solar system, with the earth in its orbit and its daily revolution, &c.—*All material rest, therefore, is relative.*

167. But the *motions* of bodies may be divided into two classes; the *absolute* and the *relative*. The absolute motion of a body is its actual change from one fixed point in space to another. The relative motion of a body is merely a change of its relative position among any other bodies with which it may be compared. The ship at anchor, as mentioned in the last paragraph, is relatively in motion when compared with the current of the river as it sweeps past

her, and the water is relatively in motion when compared with the ship. If the ship be floating with the current, she is relatively at rest when compared with the water, but relatively in motion with regard to the shores of the river.

168. We know of the existence and can reason about the nature of absolute motion; but as all visible bodies are moving, like the Peruvian gentleman already mentioned, in so many different directions at the same time, that we can not determine precisely the change of place from one point of space to another, we are unable to refer to any example of it: we must, therefore, regard it as an abstract idea of the mind, and not a thing subject to the judgment of our senses. *All known motions are relative—precisely as rest is relative.*

169. It is very evident, then, that when two bodies have a relative motion towards each other, it matters not whether we regard either of these bodies as being at rest and the other moving towards it, or consider both bodies as being in motion at the same time: if they approach each other with the same rapidity, the blow struck when they meet will be exactly equal in force in each of these cases. If you run your head perpendicularly against an open door swinging upon hinges, you will be bruised or knocked down with the same force as if you were standing at rest and the door were thrown open with the same rapidity. If a ship under way with a current strikes upon a rock, she strikes with the same force as if she were at rest, and the rock were precipitated against her with the same degree of swiftness: or, in other words, the ship *acts upon* the rock with the same force that the rock *re-acts upon* the ship. These are examples of the truth of what has been called *a law of motion*, namely, that *action and re-action are equal and opposite.* Thus; when you throw a ball against the wall, the action of the ball tends as powerfully to throw the wall over in one direction as the re-action of the wall tends to make the ball rebound in the other direction.

170. But this is as truly a law of rest as it is of motion, when bodies at rest act upon each other in any way whatever. Let a stout cord be securely tied to a hook fixed firmly in a wall; then make every effort to stretch this cord. Here it is plain that the hook draws the cord towards the wall as strongly as the cord draws your person towards the hook, and you draw the cord towards your person with like force to that with which the cord draws the hook from the wall. In these several cases action and re-action are equal, though the bodies interested are at rest. Place your hand

between a heavy weight and the surface of a table, and you perceive that the latter presses upward upon one side of your hand with the same force that the former presses downward upon the other side; so that the same law applies to bodies that attract each other, even when they are both at rest, as properly as to bodies in motion. That *action and re-action are equal*, is therefore a general law of nature, applicable to all *forces*.

171. The rapidity with which bodies move is termed their *velocity*, and velocity is measured by the distance through which the body moves uniformly in a given time. As it is convenient to have some fixed standard of time by which to measure and compare different velocities, *the second of time* has been generally adopted as the unit in such measurements: thus; if a swallow be flying at the rate of 88 feet in one second, a carrier pigeon 44 feet per second, and a garden sparrow 22 feet per second, the velocity of the swallow is said to be three times, and that of the pigeon twice that of the sparrow.

172. If you throw a stone perpendicularly against a wall with a certain degree of force, it will move with a certain velocity, it will strike the wall with a certain degree of violence, and its motion will then be arrested; but if you wish it to move with twice or thrice that velocity, it must be thrown with twice or thrice that force, and it will strike the wall with corresponding force, unless other forces, independent of your action, oppose its motion. From these observations we may deduce the following important conclusions:

173. The velocity communicated to a body by any force, is proportional to the force so applied. Therefore *motion cannot be communicated except by force*.

174. The force with which any body in motion strikes any other body with which it may come in contact, is also proportional to the velocity with which the two bodies approach each other; the effect being proportional to the *relative* and not the *absolute* velocity of the bodies.

175. If two bodies moving in opposite directions come together, the force of their striking or *collision* will be proportional to the sum of their velocities, for that will then be their relative velocity; but, for the same reason, if they be both moving in the same direction, the force of their collision will be proportioned to the difference of their velocities. For example: suppose that a locomotive engine has been left standing upon a rail-road, and that another engine,

travelling at the rate of 30 feet per second, is brought into collision with it, the force of the blow being equal to 1. Now, if the former engine were also in motion towards the other, with a velocity of 15 feet per second, the relative velocity of the two engines would be $30+15=45$ feet per second: and as the force of collision is proportional to the relative velocity, the amount of this force in the latter case, as compared with the former, is obtained from this simple statement:—As $30 : 45 :: 1 : 1.5$. But if the more rapid engine were to overtake the slower one instead of meeting it, the relative velocity would be $30-15=15$ feet per second, and, by the same rule, the force of collision would be only .5.

176. As a wall (172) resists a stone thrown against it with exactly the same force that the stone strikes it, it is very obvious that the words *resistance* and *force*, when employed philosophically, mean precisely the same thing. They are used as distinct terms merely in compliance with custom. But the cause of the resistance of the body at rest is its inertia, and the cause of the force exercised by the body in motion is also its inertia. There is therefore no difference between the inertia of rest and the inertia of motion, and the distinct use of these terms serves only to confuse the mind of the pupil by leading him to suppose that there exist two powers or principles in matter where there is really but one. For precisely the same reason, action and reaction,in natural philosophy, are the same thing. The distinction between these words is not necessary; it is merely convenient—for the stone reacts on the wall by its inertia and the wall acts on the stone by its inertia.

177. As inertia can only be overcome by force, it is obvious that motion cannot be increased, diminished, or arrested except by the application of force.

178. *Time is required to produce, arrest, or modify motion.*—As the velocity of a moving body is proportional to the force producing its motion, the inertia of a body, however large, may be slowly overcome; so that moderate forces acting constantly may communicate retard or destroy any amount of motion; but we know of no force sufficiently powerful instantly to move even the lighest article, or instantly to stop it if already in motion. Some *time*, though it may be so short as to be scarcely capable of calculation, is required to produce either of these effects. Thus, when a gun properly charged is exploded, the ball does not move with its greatest velocity until it arrives at the muzzle;

it moves slowly at first, but acquires speed so rapidly that we cannot perceive the interval between the first firing of the powder and the exit of the bullet. This is the reason why a gun of proper length will throw the ball much farther than one provided with a barrel that is too short. If a pistol be fired at a sheet of writing-paper, set in a light frame perpendicularly upon a table, the ball may overcome the inertia of the part which it actually strikes so suddenly that the cohesive force of the particles of the paper is not allowed time to overcome the inertia of the rest of the sheet and frame. The ball will then pass through the paper without shaking the frame. Bullets have passed through window panes without cracking the glass. If a cannon-ball, when its force is nearly expended, strikes the timbers of a ship, the vessel is shaken from stem to stern, and large splinters are often scattered around, though the ball be unable to penetrate the plank; but when its velocity is very great, it may pass entirely through the ship without producing any sensible tremor. Limbs have thus been shot away in battle without the consciousness of their owner, but the wound of a spent ball immediately overcomes the power of the bravest. A tallow candle shot at a board from a distance of ten or fifteen yards will be crushed into a shapeless mass, but from the distance of a few feet it has been known to glide smoothly through a piece of soft pine wood an inch in thickness.

179. When a cannon-ball is shot upward, the attraction of gravitation causes it to move more and more slowly until, *in time*, it is brought to rest; and at the next moment, the same attraction compels it to descend. At first it falls slowly, but its velocity continually increases until it reaches the earth, because the force of gravity is acting upon it *all the time*. When a ship first spreads her sails to the wind, she moves very slowly, but her speed becomes more rapid *with time*, until the resistance of the water is rendered as powerful as the wind. Her motion, previously *accelerated*, like that of the stone in falling, then becomes *uniform*, like that of a moving body when no longer urged or resisted by any force whatever. When a ship sailing rapidly before the breeze is suddenly overtaken by a calm, or has her sails furled, she does not stop at once, though the force that propelled her has ceased; her motion, previously uniform, is *retarded*, and she moves more and more slowly until the resistance of the water *has time* to overcome all her inertia. Horses pull very hard when putting a carriage in motion, but very

lightly when it is travelling rapidly: were it not for the resistance occasioned by the inequalities of the road, the friction of the nave, and other causes which constantly tend to retard the motion, they need not pull at all after the carriage is once fairly under way, unless it be necessary to increase its velocity:—it would continue to travel by its own inertia with a uniform motion. But when a heavy carriage stops very suddenly, though the horses throw themselves on their haunches, and pull back with great force, their hoofs are often forced forward for some distance, striking fire from the stones, or ploughing deep furrows in the mud.

180. Let G, Fig. 71, represent a heavy coin, laid upon a smooth card covering the open mouth of a tumbler, having a string S attached to one of its corners. If you draw this card slowly by the string, the coin will move with it; for the adhesion or the friction between the card and the coin *will have time* slowly to set the latter in motion. But, if you jerk the cord away suddenly, the inertia of the coin will cause it to linger and fall into the tumbler.

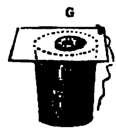

Fig. 71.

181. A man standing carelessly in a boat is thrown backward when the boat suddenly starts forward. Life has been lost by falling from the roof of a railroad car in this manner on the starting of the train. If a boat under full way suddenly strike a pier or wharf, every moveable thing in it is tost forward. When a ship strikes a rock under the same circumstances, the masts often fall over the bows. If a horse with a bad rider springs suddenly forward, he leaves his load behind; but if, when in rapid motion, he bolts or stops suddenly, the rider continues his journey and comes to the ground at some distance farther on the road. For this reason, when a person jumps from a carriage while advancing at speed, he is usually dashed forward to the loss of life or limb, and when two carriages have rushed together, the drivers have been known to change places. It is not very unusual, when vessels meet in direct collision at sea, for persons to be transferred from one to the other "without knowing how." A boy jumps much farther at the end of a short "run" than from a standing position. If a glass of water be suddenly moved forward on a table, part of the water remains behind, and if it be then as suddenly checked, part of the water will pitch forward. If a basket of eggs be carelessly and quickly set down upon a table, it often happens that the upper ranges of eggs insist upon going on while the lower

ones are brought to rest, and the weaker ones are thus crushed to pieces.

182. When one portion of a moving body is brought to rest, the remaining portions endeavour to proceed, and will do so unless the force of cohesion between the particles is sufficient to prevent them. When a stone is thrown with great force against a firm wall, the continued progress of the hindermost portions causes them to press so strongly upon the parts that first *impinge* upon or strike the wall, that the stone is broken to pieces. If a man fall from a considerable height directly upon his feet, the disposition of his head to continue its descent may cause it to press so strongly upon the bones which support it as to break the scull and cause death, though the head may not strike the ground. The breaking of the top of a vase or tumbler when the bottom forcibly strikes a table, is another effect of the same kind.

183. *A spirit level* is an instrument formed of a straight piece of glass tube, so nearly full of water as to enclose only a bubble of air, and both extremities of the tube are closed. It is intended to determine when any surface or direction is perfectly horizontal. If either end of the tube, A, Fig. 72, be elevated in the least, the air-bubble will rise towards that extremity. Now, if this instrument be placed on a horizontal table, so that the bubble may occupy the centre of

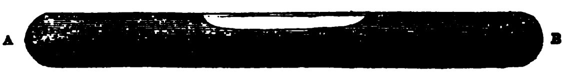

Fig. 72.

the tube when at rest, and the tube be then suddenly moved forward, the water will lag behind, forcing the air, which is the more moveable substance, towards the extremity B. The water will soon recover its proper situation, because, *in time*, it will acquire the velocity of the tube: but if the motion of the tube be then suddenly checked, the water will continue to move forward, and will force the bubble towards the extremity A. The blood in the vessels of man and animals is agitated in the same manner whenever the person is put in motion or brought to rest; and this is the principal cause of the beneficial results of swinging, riding, and all other exercises that promote the circulation.

184. *Fluid resistance arrests Motion.*—As motion is naturally uniform, and can never be increased or checked without force, you may be surprised at observing that all bodies put in motion in the immediate neighbourhood of the earth,

invariably come to rest in a short time when left to themselves. It seems reasonable that a ship should soon lose her motion when the wind ceases to blow; for the vessel does not advance through the water without much resistance. Here the resistance of the water is sufficient gradually to overcome the inertia of the ship; but why should a ball rolling along a very smooth horizontal plane move more slowly at the end of two seconds than it does at the end of one second of time? Here the principal cause of the retarded motion is the resistance of the air.

185. That air is really capable of offering very powerful resistance to the motion of bodies through it, is very easily proved. Thus: when a person attempts to run while holding an open umbrella on a calm day, he finds it impossible to make rapid progress, so strongly is he drawn back by the umbrella striking continually against the air. If, however, the holder be running before a breeze that moves as rapidly as himself, no such difficulty is experienced, for then there is no collision between the umbrella and the air. A person descending from a balloon in a parachute, Fig. 73, falls with accelerated velocity for a short time only; for the resistance of the air against the silken dome soon becomes equal in force to the gravity of the machine and its controller, and they then descend to the earth with a gentle uniform motion, like that of a ship through the water.

Fig. 73.

186. The resistance of a fluid to any moving body increases much faster than the velocity: that is; if the resistance to a body moving 1 foot per second be equal to 1, the resistance to the same body moving at the rate of 2 feet will be nearly equal to 4: for, in the latter case, the body will strike twice as many particles per second as it does in the former; so that there are twice as many little opposing forces exerted against it in the same time; and, as it is moving with double velocity, it must strike each particle with double the force. If the body move at the rate of 3 feet per second, it will strike three times as many particles, each with three times the

force, within that time, and the resistance will therefore be equal to 9—we say, therefore, that the resistance of fluids to moving bodies is nearly proportional to the squares of their velocities. Thus: if 100 square feet of canvass would drive a boat through the water at a given rate per hour, it would require about 400 feet to drive it at twice that speed. The resistance of the air thus becomes a serious opposing force to all rapid motions, and must gradually bring to rest any body not acted upon by continued force, if subjected long enough to its action.

187. *Friction arrests Motion.*—Another very important force which tends to bring moving bodies to rest is *friction* or rubbing, which is the resistance which one body opposes to the motion of another when moving over it. If you attempt to put a heavy flat body in motion along the ground, by means of a cord, you find that much more force is required than if the weight were suspended by a long string. This difference is occasioned by the friction of the body against the ground.

188. The friction of any two bodies appears to vary nearly in simple proportion to the pressure of the bodies against each other at the surface where they meet, and not according to the extent of that surface; for, it requires about the same degree of force to drag a heavy rhombic body, such as a chest, along the floor, whether it stands upon its broad bottom or its narrow end. Nor is friction increased in equal proportion when the relative velocity of the rubbing bodies is increased; and sometimes it is even diminished by an increase of velocity. It is, therefore, impossible to calculate its amount in most cases by means of any general rule, and it remains, in a great degree, a subject of experiment.

189. There is every reason to believe that the principal, if not the only cause of friction, is the irregularity of the surfaces of all bodies, none of which can be regarded as perfectly smooth. As bodies rub against each other, their particles are compelled to jolt over every ridge and are drawn by mutual attraction into every little valley: thus, the direction of motion is continually changed by forces that must retard their onward progress. Even the surfaces of crystals vary in the amount of friction which they produce. In crystals of the primitive form, and on those faces of secondary crystals which correspond with the primitive form, such as the cube of rock salt (93), the surface is extremely smooth, and the friction will be comparatively slight; but in the secondary cube of fluor spar (94), composed of primitive

octahedrons, all the faces of the crystal are formed by the projecting solid angles of the molecules: they are, therefore, less polished, and must produce more friction. In uncrystallized substances, the arrangement of the molecules being irregular, the degrees of friction defy all calculation.

190. Friction is one of the most important agents in limiting the power of machinery; and the parts of all machines that press or rub against each other by necessity, should be so constructed as to reduce as much as possible the action of this retarding force, which sometimes destroys the usefulness of one-third the force employed. In general, bodies composed of different materials produce less friction than those of the same nature: thus; when steel moves upon steel or upon cast iron, the resistance is very great; but when it rubs upon brass or gun metal, it is comparatively moderate. These differences are probably owing to the close correspondence between the hills and hollows on the surfaces of bodies formed of the same kind of matter. We often employ fluids, such as oil or soap-suds, to lessen friction. These partially fill up the inequalities of surface, and, by adhering to the moving bodies, substitute the gentle gliding of their moveable particles for the rough collision of the less yielding solids.

191. Friction not only retards motion, but often positively prevents it. The difficulty perceived on trying to drag along the floor a package of goods too heavy to be stirred by our utmost efforts, is not directly owing to its gravity; for the force of gravity only acts in opposition to us when we attempt to *lift* the package, and its sole influence in increasing the resistance to horizontal motion results from the friction which it occasions. But for the opposition produced by friction, a child might draw a rail-road train along a level track with as much ease as a toy-wagon, though more *time* would be required to communicate a respectable velocity to so large a mass of matter. It is to this power of friction, much more than to any cohesion between the threads, that we owe the strength of clothing, ropes, and every manufactured article formed by weaving or intertwining fibres.

192. Friction is not confined to solids and liquids, but is equally obvious in the movements of the atmosphere. When the muzzle of a pair of bellows is made very long, the friction of the air against the tube is so great that it will hardly "blow the fire." Attempts have been made to convey air to a furnace through tubes of great length, and the contrivers have been astonished to find that a large water-wheel or a steam engine could not force forward air enough to extinguish a

candle at the open extremity of such tubes. Solid bodies sliding upon the ground are very soon brought to rest by friction. A boat, when passing over shoals, raises much higher billows and is moved with much less speed by the same forces than when sailing in deeper water; because the bottom reacts upon the water, and the consequent friction resists its displacement. The current in the channel of a river is much slower near the bottom than at the surface, for the same reason; and when a violent storm of wind passes over even a level country, the tallest objects are more violently agitated than those of humbler pretensions.

193. Friction produces *attrition*, or the wearing away of the surfaces between which it is exercised. By its means, rivers which would otherwise rush headlong to the sea, like cars descending an inclined plane or cataracts from a precipice, are moderated in their course, and made safe and useful to man. By the attrition of water, particles are continually torn from the rocks and earthy deposites of the high ground, to settle by their weight upon the level country beneath; sometimes occasioning bars and flats, to the obstruction of navigation, and, at others, spreading layers of fertilizing mud or desolating sand over large sections of country. The effect of the simple attrition of water is no where more magnificently displayed than in the solid rocky bed of the Niagara, where the surplus water of the great North American lakes has worn a deep, dark gulph for many miles, and still continues slowly eating away the margin of the precipice over which the retreating cataract will continue to roar and thunder for ages to come as in ages past. But it is not necessary to seek for proofs of the friction of water upon solids in great phenomena and distant places: visit some steep bank of sand or gravel which is surmounted by grass or shrubbery; choose a rainy day in summer or a time of thaw in winter, and watch the water draining down the face of the embankment from the saturated soil above. Here you may witness in miniature the whole history of the formation of springs, rivers, lakes, islands, deltas, reefs, bars, creeks, bays, inlets, &c., as the little currents remove and continually re-deposite the earthy matter which lies in their way. In the resistance of the air and water produced by their inertia, and in the friction which always takes place when bodies in motion act upon each other, are found causes quite sufficient to explain the fact that all bodies in motion near the earth are speedily brought to rest, in seeming contradiction to the law that motion is perpetual in the absence of opposing forces.

194. As the velocity communicated to any body, or taken from it, is a measure of the force applied for the purpose, and as motion or the arrest of motion is the result of the overcoming of inertia by force; it follows that if the inertia of a body be increased, more force will be required to produce in it any given velocity. But the inertia of a body is proportional to the quantity of matter which it contains; because every atom has its own amount of inertia. Hence the greater the amount of matter, *or the mass* of a body, the greater will be the force required to give it any given velocity.

195. You have seen already the proof that, the quantity of matter being fixed, velocity is a measure of force applied in producing or arresting motion, (172) and in the preceding paragraph it is demonstrated that, the velocity being fixed, the quantity of matter becomes a measure of such force. Therefore the effective power of different bodies in exerting any force or producing any mechanical action is proportional both to the velocity of the bodies and the quantities of matter which they contain: and according to the rules of compound proportion, this double proportion is correctly represented by the products of the multiplication of the respective velocities by the respective quantities of matter. These products are called the *momenta* or moving forces of the bodies. Thus; if A be a body weighing ten pounds and moving with a velocity of 10 feet per second, and B be another body weighing 3 pounds and moving with a velocity of 3 feet per second; the relative momentum of the first will be $10 \times 10 = 100$, while that of the second will be $3 \times 3 = 9$.

196. The force of gravity acts upon every atom in the masses of matter between which it is exerted. That is, when a stone and the earth are attracted towards each other so as to cause the former to fall towards the latter, and the latter to rise, though imperceptibly, towards the former, this motion results not from a general and fixed action of the one mass upon the other mass, but upon the attraction of every molecule in the one, for every molecule in the other. Therefore; if one stone has twice the weight or quantity of another stone of the same kind, it is only because it contains twice the number of atoms or twice the quantity of matter. If both these bodies be allowed to fall together from the same height, they will reach the ground very nearly at the same moment, because the stone of double weight, being attracted with double force, must move with the same velocity as the lighter stone—the slight difference, if there be any, being

owing to the resistance of the air, which varies with the size and form of the body; so that a closed parachute falls much faster than an open one. You observe, then, that the weight or size of a body does not change its velocity under the influence of gravity, independently of resistance from other causes. Neither does the density of the body produce any change in this respect; for a pound of cork or feathers weighs as much as a pound of lead—that is; it contains as much matter, and has therefore as much gravity.

197. A, Fig. 74, represents a tall glass, called a receiver, which is a part of the apparatus attached to an air-pump—an instrument that will be explained hereafter. D, D, are two little brass plates moving on hinges, and capable of being kept in a horizontal position, by means of a double catch attached to the lower end of a metallic rod C, which passes through the cap of the receiver, and is provided with a handle at its upper extremity. When the handle is turned while the brass plates are held horizontally, the catch is loosened and the plates fall. Now, let a dollar, E, be placed upon one of these plates, and a light feather, F, upon the other, and turn the handle, so as to let them fall at the same moment. The receiver being full of air, the dollar will fall with great velocity, for it is very small in proportion to its weight; but the feather will descend slowly, like a parachute, because it is larger and lighter, and its form is such as to present a great surface to the resisting air. Now place the dollar and feather again upon the little plates,—set the receiver upon the plate of an air-pump, G, and exhaust the air. Then turn the handle once more, and the dollar and the feather will strike the plate of the air-pump at the same instant, because the resistance of the air is no longer felt by them. This ceases to be wonderful when you consider that if a guinea weighs as much as 10,000 feathers, it requires 10,000 times as much force to move it with a given velocity, but the earth's attraction for it will be also 10,000 times as great. Therefore dust, rain, smoke, air, and all other material substances will fall by gravity as fast as lead, if there be nothing present to oppose their motion.

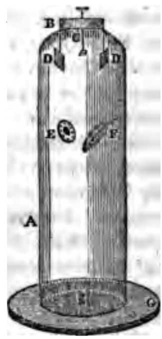

Fig. 74.

CENTRAL FORCES.

198. *Centrifugal and Centripetal forces.*—As the natural tendency of bodies in motion is to continue moving in a straight line, they cannot be bent from their course so as to move in a curve or in another straight line without force. Fig. 75 represents a lad whirling a sling. You know that the stone in a sling is continually pulling upon the hand while thus whirling, and that the faster it turns the more violently it struggles to get away; so that if made to turn too rapidly it may break the string. Here, then, considerable force is necessary to make the stone revolve in a circle, because it naturally endeavours to move off in a straight line, and the string is stretched by the force required to keep it constantly at the same distance from the hand. It struggles harder when moving more rapidly, because, while the weight remains the same, the momentum or moving force must increase in proportion to the velocity (173). If a larger stone were employed, it would pull harder even with the same velocity: because, the momentum would then increase in proportion to the weight (195).

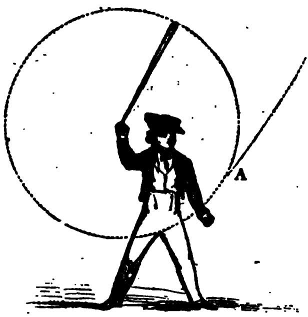

Fig. 75.

199. This tendency of bodies moving in curves to fly off in a straight line, is called *the centrifugal force*, because it tends to carry these bodies farther from a centre: but this centrifugal force is not a peculiar power in nature—it is merely one example of *inertia*.

200. The force which prevents a body from flying off when moving in a curve, or any force which draws a body towards a centre, is called *the centripetal force*. In the case of the sling, the centripetal force is the cohesion between the molecules of the string, or the friction between the fibres of which it is composed (191). But, the earth, in revolving round the sun, must have the same disposition to fly off in a straight line, on account of its centrifugal force; and as there is here no sling to restrain it, where is the centripetal force in this case? The force in this case is the attraction of gravitation. The earth gravitates towards the

sun, as a stone endeavours to sink towards the earth; and it would fall like a brick blown from the top of a chimney, if its centrifugal force did not prevent this destructive accident: it therefore necessarily revolves in an orbit determined by the balance between these contending forces. The position and the orbit of every celestial body is prescribed by the same law. If the length of the year were increased, the earth would revolve nearer to the sun, where the greater bending of its motion would give it greater centrifugal force to compensate for its loss of velocity and, consequently, its momentum. If the year were shortened, the increased momentum would carry the planet from the sun, until its centrifugal force became sufficiently diminished to permit the centripetal force of gravity once more to balance it.

201. Almost every student is led into a natural error when first taught the meaning of the term centrifugal force—he supposes that this tendency would carry a body directly away from a centre, or in the direction of a radius to a curve: but this is not the case. If the string in Fig. 75 were to break, or if the stone were set at liberty at the moment when it reaches the point A, it would fly off—at first—in the direction A B,—if the same thing should occur when the stone reaches the summit or the lowest point of the circle, it would take a horizontal direction, because, at these particular moments the stone is actually moving in the directions thus pointed out, and, because it has no power within itself to change its then existing state of motion or to alter that which is its course at the instant. Now, if you will carefully examine these three directions, you will find that they just touch the curve at the bottom, the summit, or the point A in the circle. Any straight line which just touches a curve in one point and does not *cut* or *intersect* it, is called *a tangent*;—thus A B is a tangent to the circle at the point A. It is evident that the tangent must agree exactly with the direction of the curve itself at the spot where they touch each other, and that this is also the direction of any body moving in the curve, when it reaches that spot. You now perceive the necessity of the law that *all bodies moving in curves have a disposition to fly off in the direction of the tangent to the curve at the spot where they may be.* This tendency is the centrifugal force.

202. When water is poured upon a grindstone while in motion, a portion of it adheres to the stone: but the liquid collects in particular places, in quantities greater than can adhere very strongly, and, the centrifugal force overcoming

the cohesion of the molecules, drops are thrown off from the circumference, each drop taking the direction of a tangent to the curve. This course it would continue to pursue if the attraction of the earth did not bend the motion towards the ground. When a carriage is driven rapidly round a short turn in a road, it is often thrown sideways for some distance toward the convexity of the curve; and if the wheels happen to strike an obstacle, the vehicle may be overturned with violence. Where a mountain rail-road passes around jutting precipices or sweeps into narrow ravines, arrangements are always adopted to prevent accidents from centrifugal force. In passing a projection, the inner track is made lower than the outer track, so that the car may lean very much towards the mountain, in order that gravity may counteract the tendency of the vehicle to fly off or overset towards the steep descent: but in passing a ravine, the road is inclined in the opposite direction until the carriage is sometimes made to lean over a frightful chasm, in order that it may not be dashed against the rocks above by the centrifugal force. In some such places you may travel with perfect safety at the rate of 30 miles per hour, where it would be dangerous to venture at the rate of three or four miles;—the centrifugal force being actually necessary to prevent the vehicle from falling towards the lower side of the road. Stage drivers often avail themselves of this principle, by putting their horses at fearful speed in such places. The situation of outside passengers is sometimes critical on this account; for, a person standing carelessly upon the top of a car or stage at such times is in danger of being thrown off by his inertia, at the imminent risk of life. When steam-boats "round to" suddenly at a landing, the side next the point which they are approaching rises from the water, and the opposite side sinks, sometimes to an alarming degree. When a very heavy deck load is carried, this effect may prove dangerous. Riders, to avoid similar accidents, and horses in the ring at a circus, are observed to lean very much towards the centre, and skaters always lean towards the concavity of the curve which they describe on the ice. Large grindstones or millstones connected with machinery are sometimes made to revolve so rapidly that the centrifugal force overcomes the cohesion of their molecules, and they burst asunder with tremendous violence, carrying destruction in all directions. For this reason they are strongly bound with iron. But it is often dangerous to approach the iron fly-wheel of a large factory when the machinery is allowed to act with too much rapidity;

for, these wheels have been known to break into fragments merely by the centrifugal force; the pieces sometimes passing like cannon-shot through thick stone walls, and sometimes becoming reduced almost to powder by the separation of their particles. You may whirl a bucket full of water like a stone in a sling, without spilling a drop, because the gravity of the water is then overcome by the centrifugal force. When a swift stream begins to make a bend in its course, the water wears away the soil and even the rocks upon which the current sets, and being thrown towards the opposite bank by their resistance, it immediately begins to form a new curve on that side also. Each bend thus becomes the cause of the formation of another; and thus are produced the beautiful meanderings of brooks and rivers.

203. The whirling table, represented in Fig. 76, is a philosophical instrument intended to illustrate the subject now

Fig. 76.

under discussion. In its simplest form, it is composed of two wheels coupled by a band; so that when one of them is turned by means of a handle, A, a circular motion is given to the other. The table is provided with various means for fixing upon it any apparatus upon which we wish to experiment. That which appears upon it in the figure is composed of a steel wire, B, firmly secured by a screw to the centre of the wheel F, and having a brass ring C, fixed perpendicularly to the axis, near its lower extremity. To this ring are attached four thin half hoops of brass or steel, D, D, D, D, which are also connected, at their other extremities, to a second brass ring E. In the centre of this ring there is a small hole through which passes the wire B: so that if the hoops be bent, the ring C will slide freely along the wire.

These hoops are intended rudely to represent a globe. If the wheels be set in motion, the hoops will bulge out more and more in proportion to the velocity of revolution, and, together with the moveable ring, will assume the appearance represented by the dotted lines in the figure. The cause of this change of form is obvious. The middle portion of the hoops, revolving with far greater velocity than those portions which are near the wire or axis of motion, have greater momentum and centrifugal force; they therefore fly off, and cause the hoops to bend. All bodies that are made to revolve in this manner will assume this form if their particles be capable of moving upon each other, and if they be acted upon by their mutual gravitation alone. The earth and all the planets have thus been converted into oblate spheroids. The earth bulges out 17 miles; so that a diameter drawn through the poles measures 34 miles less than a diameter drawn through the equator, and the surface of the sea under the line is 17 miles farther from the centre than the surface at the poles.

204. If a vessel of water with a spout, like a teapot, be fixed at the centre of the wheel of the whirling table, and the machine be put in motion, the water will rise in the spout and be forced out at its extremity; for in struggling to fly off in a tangent from the vessel, it is restrained by the side of the spout, and takes the only course free for it, which is along the spout. If an open basin of water be treated in the same manner, the liquid rises on the sides of the basin, leaving a hollow in the centre until, when the velocity becomes great, it flows over the edge. If a branching chandelier or hanging lamp be slowly turned upon its chain several times, and then allowed to untwist itself, the oil will fly out on all sides to a distance proportional to the tightness with which the chain is twisted. A dog dries his shaggy coat after bathing, and an elephant dispossesses himself of a clumsy rider,by violently shaking the skin in the circular direction. You will now be amused and instructed in seeking additional examples of centrifugal force among the thousands of instances that surround you, both on the earth and in the heavens.

COMPOSITION AND RESOLUTION OF FORCES.

205. *Of compound forces producing uniform rectilineal motions.*—When a body is put in motion by any force, the direction of the motion is always the same as that of the force; but when two or more forces act in different directions upon the same body, the direction of its motion appears to be

different from that of either of the forces. Let A, Fig. 77, represent a body moving under the influence of two such forces at the same time, and let one of these forces be such as, if acting alone, would compel the body to describe the right line A B, in one second of time, while the other force would compel it to describe the right line A D in the same time. Under the joint action of these two forces the body will not move in either of these lines, but will take an intermediate course between them. It will describe the right line A C. Now draw the lines C D and B C parallel to the directions of the two forces. A B D C will then be a parallelogram, and the line A C, which may be used to represent either the direction of motion or the velocity of the body A, will be a diagonal to that parallelogram. Such a figure is called the *parallelogram of motion.*

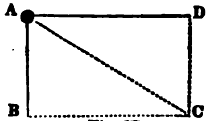

Fig. 77.

206. In order to ascertain the direction and velocity of any body moving under the influence of two forces at once, *after they have both ceased to act upon it*, you have but to draw two lines in the respective direction of the two forces, and of lengths proportional to the respective velocities which would be communicated by each of those forces separately. Then complete a parallelogram having these lines for two of its sides, draw a diagonal from their angular point, and that diagonal will represent the direction and will be proportional to the velocity of the body, under the joint action of both forces. The reason of this is perfectly plain. Under the action of the first force the body continues to move without being either accelerated or retarded, in the direction A B, Fig. 77, *or rather in directions continually parallel to that line*, all the time that it moves in a similar manner under the action of the second force in the direction A D, or in a direction parallel to A D; and it must therefore reach the line C D at exactly the same moment that it reaches the line B C. As both the motions resulting from the original forces are rectilineal and uniform, the resulting or diagonal motion must also be rectilineal and uniform.

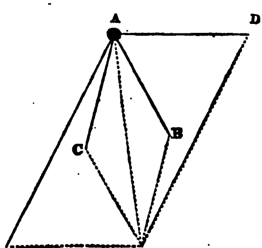

Fig. 78.

207. From this proposition it follows that it is impossible to

determine from the actual motion of any body what force may have acted upon it, unless other circumstances aid us in the decision. Thus: suppose a body placed at A, Fig. 78, to be acted upon by either of the two sets of forces represented by A B, A C, and A D, A E; the diagonal or resulting motion being alike in both cases; as is ascertained by completing the parallelograms A B F C and A D F E, it cannot be determined which of these two sets of forces produced the motion in the direction A F.

208. If a body be put in uniform motion by more than two forces acting upon it in different directions at the same time, we may still discover the resulting or diagonal motion by the same or nearly similar means. Let A B, A C, A D and A E, Fig. 79, represent the direction and velocity of the uniform motions communicated to a body placed at A. Choose any two of these lines, such as A B and A C, and upon them complete a parallelogram A B C F. Draw a diagonal, A F, and this diagonal will give the direction and velocity communicated by the joint action of the two velocities A B and A C. Upon this diagonal A F and either of the other lines—say A D—complete a second parallelogram and draw another diagonal, A G; and this line A G then represents the direction and velocity produced by the compound resulting motion A F and the simple motion A D: it therefore determines the effect of three of the four forces that have acted upon the body A. Taking this diagonal for one side of a new parallelogram, associate it with the fourth line, A E, so as to obtain the diagonal A H, which will represent the joint effect of all the velocities.

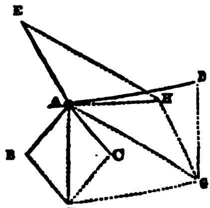

Fig. 79.

209. This process enables you to calculate the effects of any number of forces producing uniform motion, *when they all act in the same plane;* but even when they act in different planes, the same principles may be applied.

210. Let A B, A C, A D, Fig. 80, represent the directions and velocities, measured by seconds, communicated to a body A, by three forces which do not all act in the same plane. Complete the parallelogram A B, F D, and draw the diagonal A F, which will represent the combined or resulting velocities A B, A D. Then complete the parallelogram A F H C, and draw the diagonal A H. This diagonal will represent the combined velocity of the compound velocity

A F. and the simple velocity A C; it will therefore express the effect of all the forces acting on the body A. But if you complete the parallelopipedon represented in the figure, by adding the lines H E, H F, H G, E B, E C G C and D G, you will perceive at once that the diagonal A H is also a diagonal to this parallelopipedon, of which the

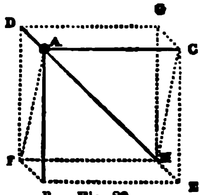

Fig. 80.

lines representing the different velocities impressed upon the body A, are measures of three dimensions of the solid; *length*, *breadth* and *thickness*.

211. *Composition of Forces.*—The velocity communicated to any one body by different forces acting separately is a *measure of these forces*; because, the weight of the body remaining unchanged, the momentum varies with the velocity only (172) and we may therefore use the lines representing the velocities as measures of the forces themselves; or of the momentum which is produced by these forces. For this reason, the process of determining the resulting motion produced by several motions operating on a body at the same time is called *the composition of forces*.

212. When two forces act upon a body at right angles with each other, they do not interfere with each other at all, though they give an increased velocity to the body. Let R R, S S, Fig. 81, represent the shores of a river, and suppose the tide to be running fast enough to carry a boat from A to C in the same time that a boat could be rowed directly from A to B if there were no current. If the boat were to start from A under such circumstances,

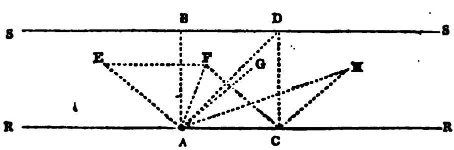

Fig. 81.

steering directly across the stream, she would move along the line A D, and arrive at D at the very moment when she would otherwise have reached B. That is; she would float as far down the river in every second of time by the force of the tide as if she carried no oars, and would advance across the river by means of her oars as fast as if there were no tide. Here the force of the oars and the force of the tide would not interfere, because they act at right angles to each other.

213. But if the two forces act at an obtuse angle, they do interfere. Let this boat, at starting, take the direction A E obliquely up the stream. If there were no current she would reach the point E in exactly the time required for crossing directly, under the same circumstances; for A E is made equal to A B. Now complete the parallelogram under the force of the oars A E and the force of the tide A C, and draw the resultant force A F. The boat will reach F in exactly the time required to carry her to D in the former case (212). But A F is shorter than A D; hence the two forces have partly opposed each other, for their joint effect has been lessened. If the boat should be rowed directly up the stream, the forces would be directly opposed, and she would move with a velocity proportional to the difference, advancing up the river if the former prevailed, or retreating down the stream if the latter predominated.

214. If the two forces act at an acute angle they aid each other, and produce an increased effect. Let the boat start down the stream in the oblique direction A G, making A G equal to A B. Draw C H equal and parallel to A G; and compound the forces of the tide and oars by drawing the diagonal A H. The boat will then reach H in exactly the time before required to reach D, B, or E: and as A H is much longer than A D, it is evident that the two forces have assisted each other. When two forces act in the same direction, it is obvious that their effect will be proportional to their sum.

215. *Resolution of Forces.*—When the direction and separate effect of one of two forces acting upon a moving body is known, and when the resultant velocity of the body is also known, the direction and separate effect of the other force may be easily ascertained. Suppose the velocity of the tide in the river just mentioned to be three miles per hour, and that in ten minutes after starting, the boat has reached the point H, one mile from A. The direction and velocity with which the boat is rowed is here evidently represented by the line C H or A G.

216. When we know the angle at which the two forces meet each other; such as A E F or A C F, Fig. 81; and also the direction and effect of the resultant force or velocity, A F, the two forces may be determined with the greatest ease by completing the parallellogram and calculating the length of the two sides A C and A E, which represent them.

217. If the angle at which the two forces meet be a right angle, the base and perpendicular of a right angled triangle

will represent the two impulsive forces, and the *hypothenuse* or longest side will represent the resultant force; because, the parallelogram of forces being a rectangle, its two diagonals are equal to each other; but it will not represent the direction of this force. Let us explain this by an example. The wind at sea is South, while a strong current is setting East, and a ship is steering North, before the wind, moving at the rate of five miles per hour. We wish to ascertain how much of this resultant motion is due to the wind and how much to the current. Let A, Fig. 82, be the position of the ship; A D the direction of her motion; A B that of the wind; and A C that of the tide. Make the distance A D equal to 5 parts from a scale of equal parts, to represent five miles, and complete the parallellogram by drawing B D parallel to A C, and C D parallel to A B, and draw the diagonal B C. Then A B will represent the force of the wind, A C that of the water, and A D the resultant force. But B C is equal to A D, and it therefore also represents the resultant force, though not its direction: and A B C is a right angled triangle of which two sides, A B, A C represent the impulsive forces, and the hypothenuse B C represents the resultant force.

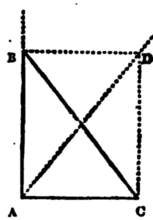

Fig. 82.

218. When we wish to determine how much of any force would be available in producing motion in any other required direction, we may consider it as a compound force and resolve it into its elements or take it to pieces. Thus, let A E, Fig. 83, represent the surface of some hard body, towards which another body, C, is moving in the direction C B, with a velocity or momentum represented by that line. From C, draw C D, perpendicular to A E. Then C D will represent the velocity or momentum with which C approaches A E, while the base, D B, represents the velocity or momentum with which C moves in a direction parallel to A E, and these forces combined are equivalent to the resultant force represented by the hypothenuse *C B.*

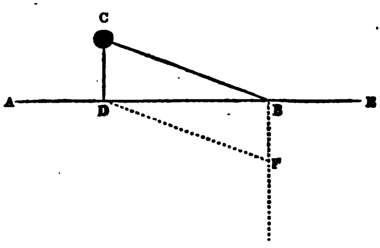

Fig. 83.

219. When bodies approach each other, it is only the velocity with which they approach each other in the perpendicular direction that determines the force with which they meet. Had the body C fallen directly upon the table A E, all its momentum would have been available in the collision; but as it moves obliquely, the portion of momentum represented by C D alone acts upon the table, while the far larger portion, D B, continues unopposed, as though no collision had taken place. If you suppose A E to be the sail of a vessel, and the line C B to point out the direction of the wind, C D will show the whole of the effect upon the sail, while D B will represent the greater force which, acting in a direction parallel to the canvass, produces no impression whatever.

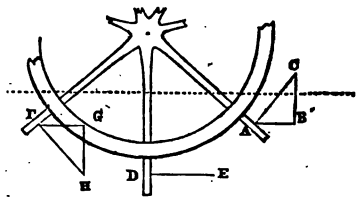

Fig. 84.

Fig. 84 is a draught of the portion of a steam-boat wheel, presenting three paddles immersed;—one, F, just entering the water; another, D, at the lowest point of the revolution; and a third, A, just leaving the water. The lines F H, D E, and A C represent the force which the paddles exert upon the water, which of course is exerted in a direction perpendicular to their surface. At the paddle D, the whole of this force is available in propelling the boat; but at the paddles A and F, a considerable part is lost by acting in a direction perpendicular to the motion of the boat. Upon A, let fall the line B A, in the direction of the motion of the boat; and upon B raise B C, perpendicular to A B. The force of the paddle A is here resolved into two forces, one of which, B C, is perpendicular to the direction of the boat's motion and can have no influence upon it. The only action of this force is to depress the boat in the water; to the surface of which it is perpendicular; and it is only by the force A B that the rising paddle A assists in propelling the vessel. Resolve the force F H in the same manner, and it will be seen that it is by the force F G alone that the sinking paddle F assists in propulsion; the remaining portion G H being expended in raising the vessel higher in the water.

220. As only that portion of the force of a moving body which tends in a perpendicular direction upon another body has a tendency to act upon it, if a body strike another

an oblique direction; as C B, Fig. 83; the strength and direction of the blow will be represented by a perpendicular line, C D, and if, after striking, there be no friction between the two bodies, the direction and quantity of motion communicated to the body struck will be pointed out by a line of equal length, B F, perpendicular to the surface at the point of contact. Hence, if an inelastic ball A, Fig. 85, be driven against another ball B, with the velocity and direction represented by A B, the latter ball will fly off in the direction B C, which is perpendicular to the surface of B at the place of contact:—Or, if B be immoveably fixed, the ball A will glance off in the direction B D,

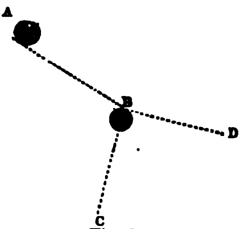

Fig. 85.

which is the direction of the surface at the point of contact. With these remarks, which are sufficiently extended for our immediate purposes, we close the subject of the composition and resolution of forces.

CONSTANT FORCES—ACCELERATED AND RETARDED MOTION.

221. We have heretofore confined our remarks chiefly to forces acting in a temporary manner and producing uniform motion: we must now consider the nature of *constant forces*, producing *accelerated* or *retarded motions*.

222. Temporary forces cease their action upon bodies when they have acquired or lost a proportional amount of velocity: Thus; two bodies coming into collision move uniformly or come to rest after collision, when no longer under the influence of the impinging force: but constant forces continue to act upon bodies at all times, whether they be in motion or at rest. Such a force is attraction. When a body is put in motion by attraction, it is not the less attracted because it moves; and as any motion which it may have acquired from this cause would continue uniformly if the attraction were to cease, the continuance of the force must perpetually accelerate the velocity of the body until it arrives at the place towards which it is attracted, unless opposed by some other force.

223. *Motion accelerated by Gravity.*—Gravity, which is a *central* as well as a *constant* force, furnishes us with admirable illustrations of the effects of such forces. Like light, heat, and all other influences, diffusing themselves in all directions from a centre, or tending in like manner

towards a centre, its action upon all material things external to the attracting body varies inversely as the square of the distance from the centre of that body. Thus; a body weighing one pound at the surface of the earth under the equator, would tend towards the earth with a force of only one-fourth of a pound at the height of 3977½ miles—this being the length of the radius of the earth at that spot. If a body suspended upon the hook of a spring steel-yard be carried to the summit of a lofty mountain it appears to weigh perceptibly less there than at the base of the mountain, because the force of the spring remains the same, while the gravity of the body is diminished: yet if weighed upon a scale-beam, the result will be the same in both situations, because in this case the gravity of the weights and the body to be weighed are equally affected. But the greatest height to which man is able to ascend is so small in comparison with the radius of the earth, that, for most practical purposes we may consider the force of gravity as *uniform* as well as constant, in all places within reach of our experiments.

224. When any body near the earth is left at liberty to obey the attraction of gravitation, it falls slowly at first, and is easily observed; but, rapidly increasing in speed, it soon appears as a mere streak of light or shade, growing fainter continually until, if small, it becomes invisible to persons standing near it.

225. As gravity is acting *all the time*, its whole force when acting upon a falling body must be measured by the time during which the body falls: and as velocity is always proportional to the force which produces it, the velocity acquired by the body must be proportional to the time. Hence; *the velocities of falling bodies vary directly as the times.*

226. When a body begins to fall by gravity, its velocity is nothing, but at the end of any given time,—a second, for example,—it becomes considerable, and may be measured. Velocities, as you have been told, are measured by the spaces described by the moving body in a given time, when in a state of *uniform* motion. Now, the motion of a falling body not being uniform, but increasing regularly from nothing, we must measure it by the space through which it would move with a *mean* or *middling* velocity in a given time, were that velocity made uniform. But, if the body fall through any given distance in the first second of time, its *mean* velocity will be acquired in half that time (225). Let us make this mean velocity the unit of our measure of velocity, and let the distance described under it in one second be our unit of

distance in measuring the spaces described by a falling body. As the actual velocity varies directly as the time of falling, the body must be moving twice as fast at the end of the first second as when it moved with its mean velocity at the end of half a second; and as the latter is assumed as the unit, its velocity at the end of the first second will be expressed by 2. If the motion could now be rendered uniform by the removal of the force of gravity, the body would describe twice the distance per second that it described during the first second. But it cannot be uniform; for, during the next second the constant force of gravity has *time* to communicate to it as much velocity as during the first second; which velocity was represented by 2. This, added to the velocity previously acquired and of course retained,—for there exists no force in action to check or destroy it—brings the body to the end of two seconds with a velocity of 4. The additional speed produced by gravity during the second period of time, being produced in the same manner and to the same extent with that produced during the first period, causes the body to fall through a distance equal to that described during the first period, in addition to that which it would describe by its acquired velocity were gravity to cease at the end of the first period. Now, the distance described during the first period was 1; and that which would be described during the second period, if the effect of gravity were to cease at the conclusion of the first, is 2: Therefore the actual distance described by a falling body during the second period will be represented by 3.

227. As gravity acts precisely in the same manner during each succeeding period of equally divided time, it is obvious that it must add a velocity equal to 2, by the end of each second, and must cause the body to describe during each second, a distance equal to 1 in addition to that which it would describe in that second without the aid of gravity.

228. You are now prepared to understand the following:

TABLE

Of the velocities acquired and the spaces described by bodies falling freely from a state of rest under the action of the attraction of gravitation.

(*a*) Times measured by seconds;	1,	2,	3,	4,	5,	6.
(*b*) Velocities acquired at the end of each second;	2,	4,	6,	8,	10,	12.

(c) Spaces described solely from the impulse of gravity during each second;	1, 1, 1, 1, 1, 1.
(d) Spaces described during each second solely by previously acquired velocity;	0, 2, 4, 6, 8, 10.
(e) Total spaces described in each second;—being the sums of the corresponding terms of the two last series;	1, 3, 5, 7, 9, 11.
(f) Spaces described between the beginning of motion and the end of each second;—being the sums of all the preceding terms of the last series up to the end of each second;	1, 4, 9, 16, 25, 36.

229. From the foregoing table we may deduce the following conclusions, which should be treasured in the memory: 1. Gravity, when uniform, adds equal amounts to the velocity of falling bodies, and causes equal additions to the space described by them, in each successive equal period of time. 2. The spaces described by previously acquired velocity in each period are expressed by a series of all the even numbers, beginning with 0. 3. The actual distances described under the influence of gravity in successive periods are expressed by a series of all the odd numbers. 4. The whole distance described in any portion of time composed of a given number of equal intervals may be found by adding together all the members of a series of odd numbers, up to the given number—the distance described during the first interval being taken as the unit of measure. Thus; the sum of three odd numbers, 1, 3, 5, gives 9—which represents the distance through which a body falls by gravity in three equal periods of time: so; the sum of ten odd numbers gives 100, which represents the distance through which a body falls by gravity in ten equal periods of time. Now, it is a property of such a series of odd numbers that if we add up all its members from the beginning to any particular point, the sum will be the square of the number of members between the commencement and that point: Therefore;—*The distances described by bodies under the influence of gravity during different intervals of time measured from the commencement of motion, vary directly as the squares of the times.*

230. As the numbers in the foregoing table have merely a relative and not a positive value, the rules laid down in the last paragraph apply equally well to all equal periods of time, all measures of distance, and all degrees of strength with which the force of gravity acts on falling bodies, so long as that force can be regarded as *uniform*.

231. It is very obvious that these results are not owing to any absolute peculiarity of the attraction of gravitation, being due solely to the fact that it is a force acting uniformly and constantly; and you will therefore require no further proof that all constant and uniform forces and their effects must be governed by the same laws.

232. Experiment proves that a body left free to fall by gravitation towards the earth, near its surface, in the neighbourhood of London, falls about 16 feet and 1 inch during the first second of time. You have then only to multiply the members of the proper series in the foregoing table by 16 1-12, to obtain the numbers expressing the relations of velocity and distance as observed in falling bodies near the earth when measured by seconds and feet. To obtain the same relations at any considerable height above the earth you should remember that the force of terrestrial gravitation varies inversely as the square of the distance from the earth's centre (229), and that the velocity of moving bodies varies directly as the force which produces their motion: You will then perceive the truth of the following statement.—As the square of the earth's radius is to the square of the distance of the moving body from the centre of the earth, so is the distance of 16 1-12 feet, to the distance through which the body will fall during the first second of time. This gives you a number to use as the unit of distance in the table, when adapting it to the height of any body.

233. As the earth is an oblate spheroid, and not a sphere, the attraction of gravitation is stronger at either pole than at the equator, because the surface at the former is nearer to the centre than at the latter station. At the poles, the fall of bodies during the first second of time is found by calculation to be 16.127 feet; while, at the equator, observation shows it to be 16.044 feet; and 16 feet and 1 inch is a near approximation to the average.

234. If we throw a stone from the summit of a precipice, we are able to judge of its height by noting the time which intervenes between the casting and the rebound of the stone, which is readily done by means of a stop-watch. Thus; if this interval be ten seconds, the height, (neglecting the

effect of the resistance of the air,—which is not very great under such velocities,—and the time occupied in the passage of light,—which is incalculably small,) will be 100 times 16 1-12 feet: or, if the interval be four seconds, the height will be 16 times 16 1-12 feet. We can also judge the perpendicular depth of caves, wells, &c., by this means; taking for our guide, instead of vision, the *sound* of the rebounding pebble: but then we must allow for the time occupied in the passage of sound; which spreads at about the rate of 1162 feet per second.

235. When a body ascends against gravity, it must lose as much velocity by the action of this force as it would gain were it falling for the same length of time: for the attraction which in the latter case would accelerate its motion downward, retards it when rising, to the same extent. Therefore a body increasing its distance from the earth's centre, loses a velocity which may be expressed by 2, and a distance equal to 1, according to the scale adopted in the last table, during each second of progress. That table, therefore, applies equally to the acceleration of falling bodies and retardation of rising bodies. If, then, a body be projected upwards, with a velocity equal to two, it will come to rest in one second, and if projected upward with twice or thrice that velocity, it will rise through two or three seconds accordingly. But in one second, it will describe a distance equal to 1, while in two seconds it will describe a distance equal to 4, and in three seconds a distance equal to 9. (*See* TABLE, *page* 98, *Series f.*)

236. Hence; bodies urged against a constant and uniform opposing force,—such as gravity near the surface of the earth—will describe distances proportional to the square of their initial or commencing velocities, or the squares of the times during which they continue to move: thus, a body shot upwards with an initial velocity equal to 2 will rise four times as high as another body projected in the same direction with a velocity equal to 1. But when bodies are projected to great elevations, allowance must be made for the diminution of the force of gravity as they ascend.

237. If a body be projected from a height in a horizontal direction, it comes to the ground in the same time and with the same velocity as if it were simply dropped from the hand. When you suddenly brush a number of small articles from a table, though some of them usually fly much farther than others, they all touch the floor at the same moment. A ball fired in a horizontal direction, Fig. 86, strikes the

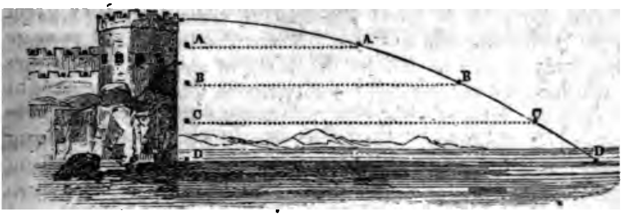

Fig. 86.

plain, if level, in exactly the same time as if it were simply rolled from the mouth of the cannon. Here gravity acts at a right angle with the projecting force, and hence the two forces cannot accelerate or retard each other. If one ball be thus dropped and another fired at the same moment, as in the figure, they will always be found at the opposite ends of the same horizontal lines, A A, B B, C C, at the same moment.

238. *Of Projectiles.*—In the last paragraph, gravity is considered as always acting in a direction perpendicular to the same horizontal line; but this is not strictly true. The direction is every where perpendicular to the surface of the earth because it tends towards the centre (16); but, for this very reason, gravity cannot be exerted in precisely parallel lines. Its direction at B, Fig. 87, is even opposite to that observed at A, while at C it is at right angles to both these directions. Even the two scales suspended at the extremities of an ordinary weighing beam take a slightly angular position in consequence of their separation. But, for most practical purposes, this angularity may be neglected in calculations relating to falling bodies whose whole course does not exceed the range of a cannon shot; for it amounts to only 1′ for each geographical mile of distance.

Fig. 87.

239. Having shown that gravity, in retarding or accelerating motion, produces invariable effects whatever may be the course of the moving body, let us consider the nature of the curves described by bodies falling obliquely. Let the horizontal line, A B, Fig. 88, represent the direction of a body suddenly projected from A; and let the equal divisions 1, 2, 3, &c., represent the distance through which the body

would move in as many consecutive seconds if its motion were rectilinear and uniform. From the instant of starting, this body begins to fall by the force of gravity, and it falls with the same accelerated velocity that it would do if allowed to obey the laws of attraction, uninfluenced by the projecting force. It therefore obeys both these forces; the motion consequent upon one of which—the projectile—is uniform, and the other motion—that of gravity—accelerated according to the law already pointed out. At the end of the first second of time, the body will have travelled in the direction parallel to the horizon as far as from A to 1: but, by this time it will have fallen a certain distance, by gravity, in a perpendicular direction. Let the distance be represented by the line from 1 to 1. In another second it will have moved forward until it comes under 2; but in these two seconds it will have fallen by gravity four times as far as during the first second (228, *f*). Drop a perpendicular from 2, and upon it lay off a distance 2, 4, equal to four times 1, 1, and this will show the position of the ball at the end of the next second of time. In three seconds the body will have arrived under 3; but by the same law, it will have fallen nine times as far as it did during the first second: therefore lay off this distance along the perpendicular 3, 9, and you determine the position of the body at the end of three seconds. Proceed in like manner for each succeeding second till the body reaches the ground: then join the points 1, 4, 9, &c., and you will form the curve A C, representing the route of the falling body. Such a curve is called *parabolic* because it is part of a *parabola*.

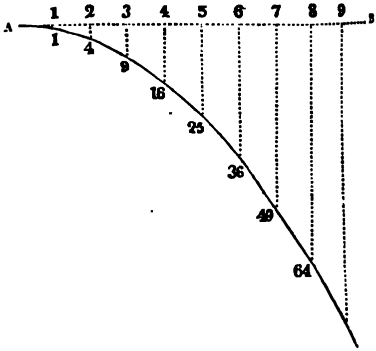

Fig. 88.

240. Here the distance through which the body falls from the horizontal line, is everywhere proportional to the square of the time during which it has been in motion, according to the general law of gravity (229). If, then, a body be projected obliquely upwards or downward in any direction, this

law determines the parabolic curve that the body will describe until it reaches the ground. In Fig. 89—the notation remaining the same—let A B represent the initial direction of the body; drop similar perpendicular lines from the points which would be reached by uniform motion in 1, 2, 3, &c., seconds respectively; and on these lines lay off the same respective distances that were employed in the last figure. Then on joining the several points thus obtained, the curve will be represented by the line A C, and this will also be a parabola. In the former figure, the body describes a portion of one side of the curve only; but in the latter it describes a portion of both sides of the curve. In this process we subtract the effect of gravity from that of the projecting force in causing an upward movement.

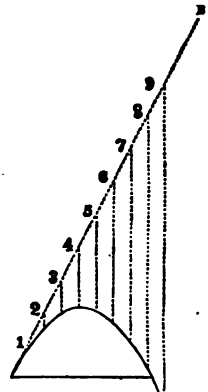

Fig. 89.

241. When a body is projected directly upward, it mounts just half as high as it would do were its motion uniformly continued during the same time in the same direction, because its mean velocity is acquired in half the time during which it moves.

242. This law is equally applicable when the body is projected *obliquely* upward. Let A D C, Fig. 90, represent the actual course of a ball projected from A, in the direction A B, with a velocity by which it would reach the point 4, if its motion were uniform, in four seconds of time, and by which it actually reaches the point C within that period. As a body reaches its greatest height, when ascending, in exactly the time which it requires to fall through the same space, the body referred to in this illustration will rise during two seconds and fall during two seconds. At the greatest height, then, it will be perpendicularly under the number 2, and A 2

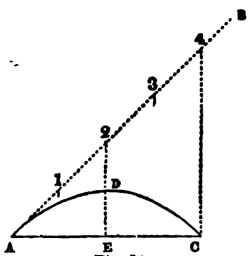

Fig. 90.

will represent the distance which it would describe during the time that it is rising, were its original motion uniform. Drop the line 2 E perpendicularly upon A E. You thus resolve A 2 into two forces or velocities: A E, which has no effect in elevating the ball, and E 2, which alone acts in that manner. This line therefore represents the height to which the body would be elevated by the projecting force alone in the time which gravity requires to destroy its upward motion. But the direction of gravity being perpendicular to A E, its action is in no degree influenced by it, and must destroy just as much of the upward motion in two seconds as if the ball were shot directly upward from E with the velocity E 2: now were this the case, you have been already informed that the ball would be brought to rest, or, its upward motion would be destroyed at half the height of E 2 (241). The summit of the parabola A D C is therefore just half as high as the point 2.

243. If a body be projected obliquely downward, we trace its track under the joint action of gravity and a projecting force in a similar manner, but instead of subtracting the perpendicular effect of gravity from that of the projecting force (240), we, in this case, add them together. Preserving in Fig. 91 the same notation as in former figures, drop, as before, perpendicular lines from the numbers representing the uniform velocity for successive seconds, and apply upon them the distances representing the effects of gravity during the corresponding seconds, and then, by completing the curve as before, we find a portion of a parabola that represents the curve of the falling body.

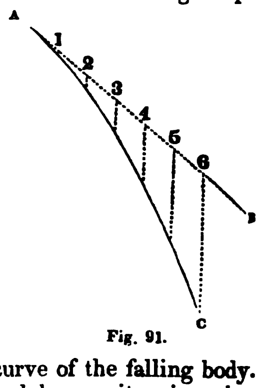

Fig. 91.

244. Parabolic motions produced by gravity give rise to many beautiful phenomena. Thus, when water first issues from a fountain jet, it appears as a comparatively narrow stream, but it soon becomes thickened by the resistance of the air. In the absence of wind, the particles being gradually pressed outwards in all directions from the axis, a certain degree of horizontal motion is communicated to them which causes the drops in falling to pursue a parabolic curvature. Oblique and horizontal jets follow the same law that governs solid bodies when projected in a similar

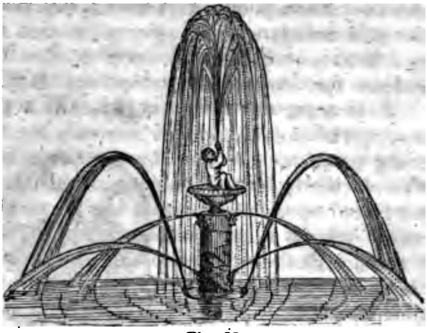

Fig. 92.

manner. These effects are beautifully displayed in Fig. 92; and the drops of water or mud thrown off from grind-stones or coach wheels in motion, furnish additional examples. In Fig. 93 you see a presentation of a bombardment and cannonade between a fort and vessels, displaying a considerable variety of form assumed by parabolæ of motion under different elevations of the line of projection.

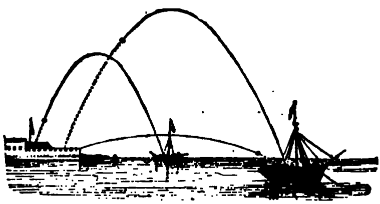

Fig 93.

245. The foregoing calculations of the motions of *projectiles* have been made without reference to the effect of the resistance of the air, which indeed exerts no very important influence upon small, heavy bodies moving through short distances at moderate velocities; but in regulating the direction of large cannon shot or bomb-shells, it is never neglected by gunners, and even the American rifleman makes allowances for it in taking aim. This resistance does not destroy the value of the rules laid down in the foregoing paragraphs; but there are many other sources of error dependent upon irregularities in the form of the projectile and its more or less rapid revolution upon its axis, upon the friction or unequal compressions of the air, and upon other causes not subject to calculation. These render the exact estimate of the course of bodies moving in what are termed *resisting*

media, such as our atmosphere, a difficult study even for the most skilful mathematician.

246. Mr. Atwood, an English philosopher, has invented a beautiful machine for demonstrating experimentally the laws of gravity. It is represented in Fig. 94. W represents a large, heavy, metallic wheel running upon a polished axle of steel, which is supported upon four smaller wheels with brass rims, called *friction wheels* because they diminish the friction of the great axle in revolving. Two of these wheels are seen at A, and one of the other pair appears between the spokes of W. They are all supported by a wooden frame B, carrying a small clock, seen beneath A, and a pendulum K, marking seconds or half seconds. This frame is secured upon an upright stand D, which is graduated to feet, inches and tenths. Upon it moves a sliding platform I, securable at any height by means of a thumb screw behind the stand: also, a sliding metallic rod, terminating in a small ring, and securable in the same manner. A light cord is thrown over the wheel W, carrying at its opposite extremities the equal weights E, F.

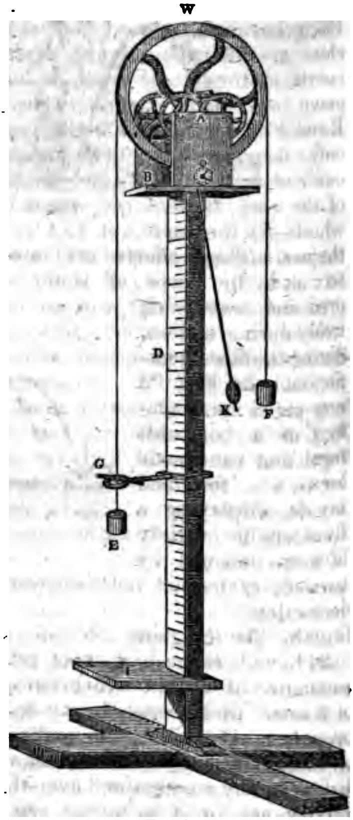

Fig. 94.

247. Now the weights E, F, being equal, exactly balance each other; but if a small rod or other weight G be laid upon E, it will gravitate more powerfully than F, and will cause the wheel to turn.

248. The greater the amount of inertia to be overcome while the force of gravity acting upon a body remains the same, the longer is the time required to communicate any given velocity and the slower the motion acquired in any given time. If the little rod G were permitted to fall freely by its gravity, it would describe sixteen feet and an inch, or 193 inches in one second; but as the other parts of the machine are all balanced and at rest before G is added, the inertia of the whole machine must be overcome by the gravity of G alone, when it is placed upon E. Now suppose E and F to weigh each eight pounds troy, and G an ounce only: then the inertia to be overcome by the gravity of one ounce of metal in this case—even if we neglect the weight of the cord, that of the wheel W and that of the friction wheels—is the inertia of 193 ounces of matter; and hence the motion communicated to the whole mass during the first second, by the gravity of G alone will be only the one hundred and ninety-third part of that acquired when falling freely during one second: that is, the bar will fall one inch during the first second, four inches in two seconds, &c., and the table at page 98 becomes directly applicable in all respects to the velocities acquired, and the distances described by E during successive seconds. Here it is evident that by regulating the size of the weights E and F, and that of the bar G, we can procure accelerated or retarded motions of any desired velocity; so as to observe their laws at leisure. By means of this instrument—due allowance being made for a little friction which can not be entirely destroyed—all the laws of accelerating and retarding forces have been fully demonstrated in series of actual experiments requiring but little mechanical skill.

249. *Of Elliptic motions produced by Gravity.*—The parabolic curvature of projectiles is observable only in those of a small range;—and it is now proper to speak of the course of bodies moving through greater distances, on which the force of gravity acts in widely different directions at different points in their course. Were the resistance of the air removed, a cannon ball shot from the top of a high mountain would probably fall at the distance of 40 or 50 miles. With still greater projectile force,

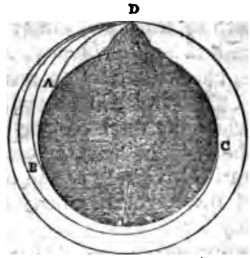

Fig. 95.

it might travel as far as A, Fig. 95, which rudely represents the earth and a mountain, D, from which the body is supposed to be projected. Now the direction of gravity at A is very widely different from that at D,—both tending towards the centre of the sphere—consequently, the curve A D, representing the course of the ball, can not be a parabola; see Fig. 88, page 102. By still greater projecting force, the ball might be carried, even through the atmosphere, to B or C; and hence it appears that its velocity might be so far increased as to render the centrifugal force equal to gravity. Under such circumstances, the ball would not approach the earth at all, but would return to the top of the mountain from which it started; where, being placed in exactly the same condition of motion, direction, and distance from the centre of attraction as at first, it would continue to revolve round the earth as a planet, ever after. The projectile force required to produce such a little moon or satellite to the earth in the absence of an atmosphere, would be but ten times as great as that which sometimes propels a cannon ball; and accidents of this kind may have occurred from the vast forces exerted by volcanoes in our own and other planets. Some persons believe that certain meteors are bodies of this character.

250. If all the attractive power of the earth were concentrated in the centre, and if the impenetrability of matter did not prevent the ball in the last illustration from proceeding after it comes to the ground, it might be supposed that when falling in either of the curves D A, D B, D C, Fig. 95, it would continue to revolve in a spiral line until it arrived at the centre; and also, that when the force was sufficient to carry the returning ball higher than the mountain, it would go on revolving in a spiral enlarging for ever. Such would be the results if the centrifugal and centripetal forces were varied in simple proportion when the orbit of a body revolving around a centre of attraction is enlarged or diminished; for, in this case, either of these central forces having once gained an ascendency, there would be no force in existence to check the motion resulting from that ascendency.

251. But it is proved, both by theory and experiment, that while the force of gravity varies inversely as the square of the distance from the centre of attraction, the centrifugal force varies inversely as the cube of that distance—the momentum of the revolving body remaining the same. Hence, when any force drives such a body nearer to the centre than its proper orbit—where the two central forces are balanced,—the increasing centrifugal force compels it to fly off again to a pro-

portional distance, and when any force drives the body beyond its proper orbit, the rapidly diminishing centrifugal force allows gravity to compel its return to the proper distance: thus; though thousands of causes are constantly disturbing the regular movements of every planet, its own inertia and the balance between the central forces as constantly restore it to its proper position. Therefore, under the circumstances mentioned in paragraph 250, the cannon ball could never reach the centre, but, after approaching within a certain distance of it, would fly off again and return to the mountain top, in an elliptical orbit. If falling bodies ever pursue a spiral course, as represented in Fig. 95, it is because the resistance of the air or some other opposing force prevents them from pursuing an elliptical track. The proof of this fact, however, though simple to the mathematician, is almost too puzzling to beginners. In the absence of an atmosphere, a body projected with such force as to pass half round the world, though it might fall from the height of a million of miles, and might almost graze the surface at the point of its nearest approach, would never fall to the ground, but would revolve round the earth as a satellite or mundane comet, according to the momentum and direction originally impressed upon it; which direction therefore determines the dimensions of the orbit.

252. Kepler was the first to observe that the planets actually revolve in elliptical orbits, and found that a line drawn from the centre of attraction to the moving body always describes equal spaces in equal times. Let C, Fig. 96, represent a centre of attraction, and A a planet revolving round it. Then the line B A, which joins them, will describe equal spaces in equal times. Thus; if A revolve as far as B in one month, year, or other period of time, it will reach D in another equal period, making the space A C B equal to the space B C D; and it will observe this law throughout its whole course. Kepler also ascertained that there is but one point in the orbit of every planet where the velocity of the planet is greatest; which is the point nearest to the centre of attraction (Fig. 96, E): and one other point, where the velocity is slowest; which is the point farthest from the centre (A). Between these points he found

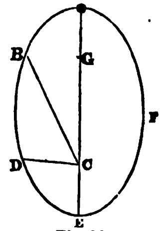

Fig. 96.

the motion to be regularly accelerated while the planet is approaching the centre, and regularly retarded while it is retiring from the centre. Now, there are but two points within an elliptical orbit, round which a body can revolve with a velocity regularly accelerated and retarded, in such a manner as to describe equal spaces in equal times; and these points are the foci of the ellipse, (C and G). Therefore, by necessity, the centre around which all the planets revolve must be in the common focus of all their elliptical orbits. It was demonstrated by Newton that when the attracting force varies, like gravity, inversely as the square of the distance, the only possible curves that the orbit of a projectile can assume and maintain under the influence of disturbing causes, are the three conic sections—the *ellipse*, the *parabola*, and the *hyperbola*; and the character of the curve will be determined by the velocity of the body. But, as the parabola and hyperbola are curves which do not return into themselves, like the circle and the ellipse, they can never form entire orbits. A very large ellipse may resemble either of the curves just mentioned so closely that in examining a relatively small portion of one extremity only, we may be unable to distinguish between them. This is the case with the orbits of many comets, of which but a small portion is visible; and it is then impossible to foretell the moment of their return, or indeed, to say that they will ever more revisit our system. If the orbit of a comet be really parabolic or hyperbolic, there is reason to believe that it is a wanderer from some distant group of worlds, and that if destined once more to visit the regions of the sun, it must be owing to some modification of its orbit, the result of attractions far beyond the reach of calculation.

253. *Action of constant forces on bodies moving along inclined planes and curves.*—The pendulum not only enables us properly to divide that most valuable of all possessions,—*time*,—but it furnishes us with accurate means for measuring the figure of the earth, and casts light upon a host of questions in mechanics and astronomy; but before we touch upon this interesting subject it is necessary to explain the application of the laws of gravity to the motions of bodies under the influence of gravity upon inclined planes and curves. And in these remarks we throw aside all consideration of the resistance offered to the moving body by friction and atmospheric resistance.

254. Let A B C, Fig. 97, represent an inclined plane; C B being its length and A C its perpendicular height: and

Let D be a body left free to roll down the plane; also let D E represent the whole force of gravity acting upon D, measured by the distance through which it would fall in any given portion of time, such as one second. Resolve this force into two, by drawing the line

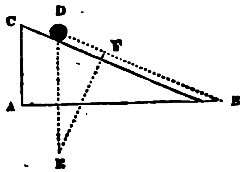

Fig. 97.

D B parallel to the plane, and the line E F perpendicular to D B. F E will then represent that portion of the force of gravity which acts perpendicularly upon the plain, and is consequently destroyed by its re-action; while D F will represent the portion which urges the body down the plane. D will therefore descend to F in exactly the time that it would fall by the whole force of gravity to E: because the velocity of moving bodies is proportional to the force producing it. Hence the force of gravity urging the body down the plane is to the whole force of gravity as D F is to D E; and the time required to descend through D F under the force D F, is to the time required to fall to E, under the whole force of gravity, as D E is to D F. But, because the two triangles A B C, D F E are similar to each other, D E is to D F as C B is to C A—as the length of the plane is to its height.*

255. These facts establish the truth of the following laws; which should be committed to memory:

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* As you are supposed to be unacquainted with geometry, this fact must be illustrated.—As D F is parallel to C B, and D E to C A, the inclination of the two first lines towards each other is exactly the same as that of the two last: that is; the angle E D F is equal or similar to the angle A C B. But the angles D F E and C A B are both right-angles, and therefore equal to each other (58). Therefore, in the two triangles D E F and A B C, two angles of the one triangle added together are equal to two angles of the other triangle added together. Now; the three angles of every triangle are equal to two right angles, or 180° (66). If, then, you take the sum of the two angles at D and F from 180° you obtain the dimensions of the angle at E; and if you take the same sum, or—what is exactly equal to it—the sum of the angles at C and A—from the same 180°, you obtain the dimensions of the angle at B. The angle at B, which is in the triangle A B C, is therefore equal to the angle at E, which is in the triangle D E F—so that in these two triangles the corresponding angles are all equal to each other—or, their sides are inclined towards each other in the same manner. Thus it is shown that two triangles are perfectly similar in form and differ only in size. Their corresponding sides, then, are proportional to each other in all respects; and D F is to D E as the height of the plane is to its length.

(*a.*) The force of gravity acting upon a body placed upon an inclined plane is to the whole force of gravity acting on the body, as the height of the plane is to its length.

(*b.*) The time occupied by a body in descending an inclined plane is to the time occupied in falling freely through the height of the plane, as the length of the plane is to its height. Therefore;

(*c.*) The times occupied in falling down different inclined planes of similar height, by gravity, must vary as the lengths of the planes; because the heights are all equal.

(*d.*) Gravity acts on bodies upon inclined planes as a constant force, subject to all the laws which govern the action of gravity upon projectiles (231). But the distance described by bodies falling by gravity or propelled by any other uniform and constant force, varies as the squares of the times (229). Therefore:

(*e.*) The times occupied in descending different inclined planes of the same inclination vary as the square-roots of their heights:

Moreover, under the action of constant forces, the velocities vary as the times (Table, page 97, series *a* and *b*). Therefore:

(*f.*) The velocity acquired by descending different planes *of equal perpendicular height* is always the same.

But the perpendicular height of any plane may be regarded as in itself representing the most inclined of all possible planes. Therefore:

(*g.*) The velocity acquired by descending any inclined plane is equal to that gained by descending through the perpendicular height of the plane.

256. A very important problem in the theory of inclined planes is this: The descents of bodies through all chords of a circle drawn from either extremity of a diameter perpendicular to the horizon are completed in equal time; and that time is precisely what is required for a body to fall freely through the entire diameter of the circle. In order to explain this fact we must inform you that every angle formed be-

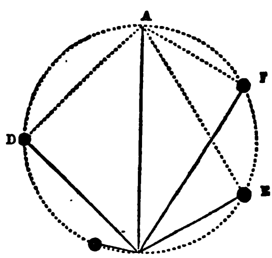

Fig. 98.

tween two lines drawn from the opposite extremities of a diameter to any point in the circumference of a circle must be a

angle; when you study geometry you will learn the rea-
f this. The angles D, C, F and E, Fig. 98, are therefore
ght angles. Now; suppose the several little balls re-
nted at these points to be descending the several in-
l planes D B, C B, F B and E B. They will all reach
oint B in the same time exactly. For; let A B repre-
he force of gravity, or the distance which a body would
n the time required for the ball D to reach the point B.
D A, and because the angle D is a right angle, the force
avity is resolved into two forces,—A D, which is perpen-
ar to the plane, and is therefore overcome by its resist-
, and D B, which represents the portion of the force of
ty which urges the ball down the plain. In the same
ner you may prove that the lines C B, F B and E B
ally represent the forces urging the three remaining
down their several inclined planes. But the distance
ibed by a body under the action of any force in a given
is proportional to that force: Therefore these lines re-
nt the distances which any bodies would describe in
nding these corresponding planes during any given
on of time; and therefore, if the balls all commenced
motion at once, they would reach B at the same instant.
the diameter A B is but the perpendicular into which
hords would vanish if continually increased in length;
at it may be regarded as an inclined plane in a semi-
e with the greatest possible degree of inclination, and its
nt would therefore be performed in the same time with
of the chords. By reversing the figure you will per-
e that the same rule applies to the chords which termi-
in the opposite end of the diameter at B. This propo-
n, which might have been proved in a very few words
e aid of mathematical expres-
, must be thoroughly under-
l by the pupil before he
nces one step further in his
es.

7. If a body descend a num-
f different inclined planes in
ssion, as represented in Fig.
ts velocity will be continually
lerated; but it will not be
rmly accelerated; for, the
nations of the planes being
us, the accelerating force
avity will also vary on each

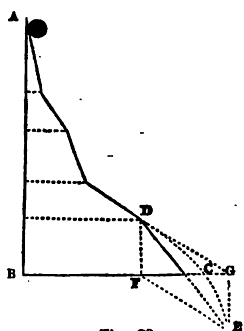

Fig. 99.

of the planes. Moreover, the direction of motion being suddenly changed, there is a loss of momentum whenever the body passes from one plane to another of less inclination, which checks the previously acquired velocity; as when the body descends from the first to the second plane in the figure.

258. If the acquired velocity be very great when the body arrives at the commencement of a plane of greater inclination, it may be carried entirely off from the surface by that portion of the motion which takes place in the horizontal direction; and it will then leap from the surface to the next plane or to the ground in a parabolic curve. Suppose, for instance, that the velocity acquired by the body on reaching D would carry it to G, if continued uniformly, while the force of gravity alone would carry it to F. Complete the parallelogram of these forces and draw the resulting force D E. It is evident that the joint action would carry the body to E in the same time that it would require to fall from a state of rest through the distance D F. But on passing D, the body is acted upon exactly like a projectile, and must pursue a parabolic curve D C E, like that represented in Fig. 91, page 104. Thus, rapid streams of water leap and bound down oblique precipices, instead of flowing evenly over the surface.

259. It is evident, then, that the velocity gained by a body in descending a series of inclined planes of visible length and diminishing inclination *is not equal* to that which would be acquired by descending freely through the entire height of the series, as in the case of the single plane (255, *g*); because every sudden change in the direction of the motion is attended with some loss of velocity (257). But when a body moves down a curve, this retarding cause does not exist; for, a curve may be considered as composed of a series of inclined planes, A B, B C, C D, Fig. 100, which planes must be regarded as infinitely small; so that, here, there is never any *sudden* change of direction to check the velocity.

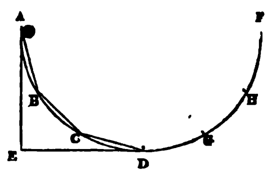

Fig. 100.

Still, the acceleration of the motion on a curve is not uniform, as on a single inclined plane; because, if the body be moving down a concave surface, the direction of the curve becomes continually more opposed to the accelerating force of gravity, and if the surface be con-

vex, as A D, Fig. 101, resistance to this force continually diminishes. In either case, however, the body arrives at D with the velocity which it would acquire in falling freely from A to E, as if the curve were a simple inclined plane.

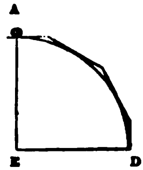

Fig. 101.

260. If a body be urged up a curve or an inclined plane with any given velocity, it will rise as far as it would fall in acquiring that velocity; for the effect of gravity in opposing the upward motion is precisely similar to that which it exercises in accelerating the downward motion. Now, let A, Fig. 102, be a metallic rod suspending the heavy body B freely from the fixed point C. This instrument represents the common pendulum. Let D E be a graduated scale of equal parts, curved into the arc of a circle of which the point C is the centre. If B be drawn towards D or E, through any number of degrees of the scale; as, for instance, to F; it will descend by gravity, with increasing speed, down the curve F B, and will thus acquire the velocity which would result from falling freely through the perpendicular height of the curve. This velocity will carry it up the curve B H, to H, which is at the same perpendicular height as F. Here, it must re-commence its descent, and will therefore return to F. Thus it would continue vibrating for ever, if atmospheric resistance and friction were absent. This law is equally applicable to all hanging bodies that are free to move under the influence of gravity, from the pendant chandelier to a child amusing itself in the swing.

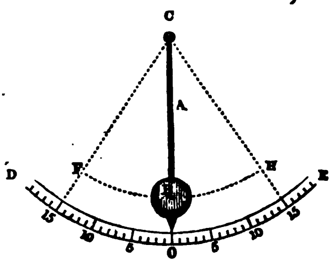

Fig. 102.

261. Weight has no effect upon the velocity of bodies moving *freely* on inclined planes or curves (255, *d*), but the weight of a pendulum does not fall freely; for the rod of suspension A, Fig. 102, weighs something; and the various parts of the rod move around the centre of suspension C, in similar curves of different lengths; yet, by the stiffness of the rod, they are all compelled to reach the bottoms of their several curves at the same moment. And here we must ask your closest attention.

262. Let C B, Fig. 103, be a pendulum rod, with the principal weight attached at B, and the centre of suspension at C. Let the weight B, with the rod, be drawn to one side until it reaches F, and then allowed to swing back by gravity. It is evident that the atoms situated at A, D, and F, must describe the curves A H, D I, or F B, respectively; and that the stiffness of the rod will compel every atom throughout the length of the rod to describe its appropriate curve *in the same time*. Now; suppose all the matter in the rod from C to A to be concentrated around the point A; all the matter from A to D, around the point D; and all the matter from D to the end of the rod, including the great weight B, around the point F: and let each of these portions of matter be supposed to be separately connected with the point of suspension, C, by some inflexible bond having no weight, or being uninfluenced by gravity.

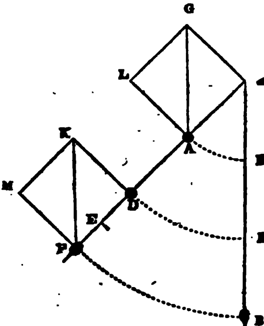

Fig. 103.

263. Bodies moving in curves advance, at all times, in the direction of tangents to the curves; and a tangent to a circle is always perpendicular to a radius terminating in the tangent: Therefore L A, K D and M F, which are tangents to the several curves A H, D I, F B, at the points A, D, and F, being all perpendicular to the radius C F, must be parallel to each other; and the direction of motion of the bodies A, D, and F, must be perfectly similar at any given moment during their descent:—*Therefore the accelerating force of gravity acting upon each must be the same.* To make this still more clear, let A G, Fig. 103, be a line drawn perpendicular to the horizon, representing the whole accelerating power of gravity acting on a body free to fall; and draw G L perpendicular to the tangent L A. Then, by the resolution of forces, L A represents the accelerating power of gravity acting on the body A; the remaining power of gravity represented by L G having no tendency to cause A to descend towards H, because it acts at a right angle with that motion. Upon F raise the perpendicular F K, making it equal to A G, and let fall the perpendicular K M upon the tangent M F; then M F will represent the accelerating force of gravity acting upon the body F. Complete the parallelograms of forces M D and L C, and as these are

rectangles having their diagonals G A and K F of equal length, they must be of equal size in all respects: hence the side M F is equal to the side L A, and as these sides represent the accelerating force of gravity acting upon A and F, these forces must be equal to each other. The same thing may be proved in the same manner of the body D, and of every atom in the pendulum rod. Therefore; *every atom in a vibrating pendulum is urged onward by the same accelerating force.*

264. But bodies under the influence of equal forces, if free to move, will describe equal spaces in equal times: Therefore, in the time required for the body D to descend to I, the body A, if unchecked by the rod, would travel far beyond H, while the body F would not be able to reach B. To prove this experimentally, secure several small weights to a light string, at the distance of a foot or more from each other; then suspend the cord upon a nail by one extremity, and put the whole series into a state of vibration. Each weight will then be seen endeavouring to vibrate in its own proper time; those nearest the centre of suspension *beating time* most quickly; and thus they will jerk each other into apparent confusion of motion, counteracting each other's efforts, and very soon bringing the whole to rest. But if you suspend all the weights together at one spot, the vibration will be regular and will continue for a long time. Now, the mere fact that the weights A, D, and F, Fig. 103, are bound together in the simple pendulum by an inflexible rod, does not prevent these weights from being acted upon by gravity to the same extent as if each were freely suspended to the end of its appropriate rod:—the weight A still struggles to drag the rod downward, urging D beyond its ability to follow, while F still holds back, by its inertia, and the whole being thus compelled to move in concert, the actual motion of the rod is the result of the joint action of all these contending forces.

265. There must be, therefore, some point, E, between A and F, where the disposition of some of the weights to hurry forward and that of the others to retard the motion will just balance each other; and it is evident that if all the matter of all the weights were concentrated round this point, the pendulum would vibrate in the same time as when they are distributed. This point is called *the centre of oscillation;* and as the pendulum always acts as if all its substance were concentrated in this spot, the distance between the centre of suspension and the centre of oscillation, C E, is always

considered and spoken of by philosophers as *the true length of the pendulum.*

266. When bodies act or re-act upon each other mechanically—and by *mechanics* we mean the science that treats of the effects of force and motion upon the condition of bodies—their weight is one of the elements entering into all calculations of their momentum or force of action. Thus; although *the velocity* of a body moving down an inclined plane, or that of a pendulum with a single weight concentrated at the centre of oscillation, is in no degree influenced by the amount of the weight, this element is very important in calculating the effect of the pressure on the plane or the stress upon the rod; *because these bodies have a mutual action on each other,* not wholly dependent on their velocity. As the three bodies A, D and F, Fig. 103, have all an action upon the rod, and also upon each other through the medium of the rod, their weight must be an element in calculating their effect. The two first are always striving to accelerate the motion of the rod, while the last endeavors to retard it, and these efforts exactly balance each other at the centre of oscillation, E, round which point they tend to bend the rod, or make it revolve. Now, if any of these bodies be increased in weight, they will display proportionally more power in accelerating or retarding the motion of the rod. If A and D are increased, the accelerating forces will be greater and the pendulum will beat more rapidly. When we have explained the nature of the lever, you will comprehend that this change in the distribution of the weight must elevate the centre of oscillation, bringing the point E nearer to the centre of suspension C: the increase of these accelerating forces or weights therefore diminishes the length of the pendulum. But if F be increased, the retarding force becomes more powerful, the pendulum is lengthened, and its beat is rendered slower.

267. The time occupied by any pendulum in performing a single vibration, *oscillation,* or beat, will be nearly the same whatever may be the length of the arc through which it moves. If the motion of bodies descending curves were uniformly accelerated, as is the case when they descend inclined planes, the oscillations would be precisely equal, like the times of descent through the planes forming chords in a semicircle, Fig. 98; but as this motion is not uniform, there is a sensible difference between the times of a long and a short vibration. When the arcs described are small, the chords and the arcs agree so nearly in length that the same

law of descent applies to both, with sufficient accuracy for all practical purposes; and hence the beating of a simple pendulum furnishes a sufficiently accurate measure of time to regulate the motions of any ordinary clock. But great accuracy requires the correction of another source of error. Caloric, as you have been informed, expands all bodies, and cold contracts them; therefore every variation of temperature either lengthens or shortens an ordinary pendulum; so that if no change be made in the distribution or position of the weight upon the rod, a common clock will go faster in winter than in summer.

268. Much ingenuity has been exercised in contriving pendulums which may regulate themselves under changes of temperature, by means of machinery, so as to keep the centre of oscillation always at exactly the same height. These are called compensating pendulums, one of which, called *the gridiron pendulum*, is represented in Fig. 104. The principal suspension rod passes from the centre of suspension C, through a horizontal metallic plate B B, *to which it is not united*, and terminates in another metallic plate A A; and here the rod is firmly attached. This is the middle rod in the figure. It is made of steel. Two rods or bars of brass, D, D, extend from the plate A A to the plate B B, to both of which they are permanently united. Two other bars of steel, F, F, are secured to the plate B B, and descending, pass through the plate A A without being attached to it. These last rods are united by a cross piece G G, to which is attached the weight E. Here you perceive that if the central rod suspended from C is elongated, the plate A A attached to its lower extremity must descend, and would drag after it the plate B B, which slides freely on the rod, were not this tendency counteracted by the expansion of the bars D, D, which tends to thrust the plate B B upward, towards the centre of suspension. But while this double action is going on, the steel bars F, F, are also elongated by the heat; and, as they slide freely through the plate A A, the cross piece G G with the weight attached to it would be allowed to descend through a distance equal to that elongation, if the plate B B remained permanent at the same distance from the point C. Thus, under an increase of temperature the three steel rods tend to lengthen

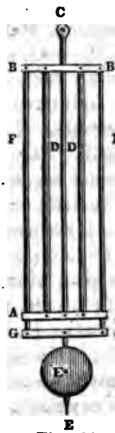

Fig. 104.

the pendulum, while the two brass bars tend to shorten it; but when the temperature is diminished, the steel bars tend to elevate the weight, and consequently the centre of oscillation, while the brass bar tends to depress them. Now, brass expands and contracts twice as much as steel under moderate changes of temperature; hence, if the central rod be lengthened one inch by expansion, thus lowering A A to that extent, the brass bars D D will be lengthened two inches; so that they will not merely prevent B B from subsiding, but will actually thrust it upwards one inch nearer to C. This elevation is just sufficient to compensate the depressing tendency of the two exterior steel rods F F, which would also be lengthened one inch. These expansions and contractions, by thus counterbalancing each other, keep the weight E and the length of the pendulum at all times very nearly unchanged. Clocks provided with pendulums acting on this principle, are astonishingly accurate and free from the influence of the seasons. They are chiefly employed for astronomical purposes.

269. *The Metronome.*—As the length of a pendulum beating seconds of time is inconvenient for many purposes, an instrument called the *metronome* has been contrived, which measures time with sufficient regularity, and may be made to beat with any required rapidity. This instrument is a kind of double pendulum, the rod being suspended at a point but shortly removed from its centre, C, Fig. 105. A considerable weight D, is placed below the centre of suspension. It is capable of sliding upon the rod, and is fixed by means of a thumb-screw. Another weight E — usually smaller — slides along the rod above the centre of suspension, and is secured by a similar screw. While the metronome is vibrating, whenever D is descending, E must be rising, and the reverse. The gravity of E therefore constantly opposes the gravity of D, and the pendulum vibrates by the difference of these forces only. If this difference be rendered less and less continually, by moving the weight D towards the centre of suspension or the weight E away from that centre, the accel-

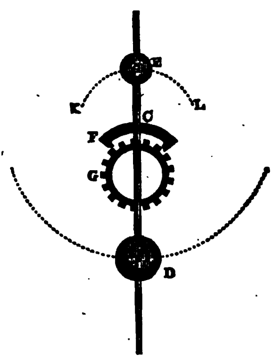

Fig. 105.

erating force must be diminished proportionally until, when the two bodies balance each other, the rod will not vibrate at all. By means of this little instrument we may imitate the beat of simple pendulums of all possible lengths. It is chiefly employed by singers and speakers in measuring the time of music and the quantity of syllables; being usually kept in motion by clock work connected with what is called *an escapement;* the small cog-wheel G and the *anchor* F representing the manner of the connexion, which is similar to the *escapement* of a common clock.

270. *The Cycloidal Pendulum.*—A pendulum may be made to beat in exactly equal times, whatever the angle of oscillation may be; though it cannot do so in circular arcs. There is a curve called the *cycloid,* in which the motion is thus regulated; but the apparatus required to make a body vibrate in such a curve prevents it from being generally useful. A cycloid is generated by any point that may be chosen in the circumference of a circle, when the circumference is made to roll along a straight line until it performs a complete revolution. Let W, Fig. 106, represent a wheel revolving along the line A H; and let A, the lowest point of this wheel, be chosen as the generating point. While the wheel makes an entire revolution, the point A must mount to C and re-descend to H, thus describing the curve A C H. This curve is a cycloid.

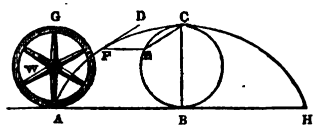

Fig. 106.

271. It is necessary here to mention a few of the properties of the cycloid. The base of this curve is equal to the whole circumference of the generating circle; because the circumference is accurately measured along the line at each complete revolution of the circle. Every arc in half a cycloid has twice the length of the corresponding chord of the generating circle: thus, the arc F C has twice the length of the chord E C; F E being parallel to the base A H. Therefore; the half cycloid A C has twice the length of the diameter B C, and the whole cycloid measures four times the diameter or eight times the radius of the generating circle. If any line (E F) be drawn parallel to the base of the cycloid, the tangent to the cycloid (F D) at the point of intersection (F), will be parallel to the corresponding chord of the generating circle (E C).

272. Invert Fig. 106, and you perceive that the accelerating

force of gravity acting on a body descending along a cycloidal curve is at all times equal to that which the same agent exerts upon a body descending corresponding parallel chords in a semicircle, because the tangent F D is always parallel to the chord E C. But, the cycloidal arc being always just twice as long as the corresponding chord, it will be traversed by the descending body in exactly twice the time. Now the descent along all chords in a given semicircle is performed in equal times (256); therefore, the descent along all arcs of a given cycloid will be performed in equal times. Hence, a pendulum vibrating in a cycloid must vibrate in equal times, whatever may be the extent of its vibrations.

273. Let C A and C B, Fig. 107, represent the surfaces of two equal semi-cycloidal bodies united at their extremities at the point C, the point of suspension of a pendulum C D, of which the suspending rod is a flexible spring or cord. When the weight D is made to vibrate from A to B, the spring or cord is wound alternately around the curved surfaces C A, C B, and the weight describes the entire cycloidal circumference A D B, forming a pendulum of the character described in the last paragraph.

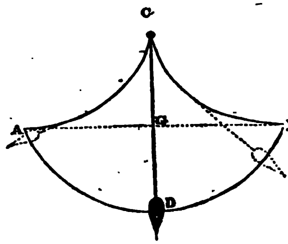

Fig. 107.

274. One of the most interesting questions in the history of pendulums is the relation between their lengths and the times of their vibrations. It is easy to prove, from data already given, that *the beats of different pendulums vary as the square roots of their lengths;* but the proof would require more space than we can here appropriate, and we must therefore ask you to receive the fact on trust, for the present. (255, *e*)

275. The length of a pendulum vibrating seconds at London has been found by experiment to be accurately 39.13929 inches; hence, by the law just laid down in the last paragraph, the length required for a beat of half seconds would be $\frac{1}{4}$ that length, or 9.785 inches nearly; while that required for a beat of three seconds would be 9 times the former length, or more than $9\frac{3}{4}$ yards.

276. The rapidity of the beat of a pendulum varies also with the intensity of gravity at the spot where the instrument is placed; and the earth being an oblate spheroid, a pendulum that would beat seconds at Philadelphia, would vibrate in less than a second in Nova Scotia, and would

require more than a second to complete an oscillation in …il. A clock keeping correct time at the foot of a mountain a mile in height, will go perceptibly slower if carried to the summit, because it will there be one mile more distant from the centre of the earth. The time of vibration varies directly as the distance from the centre; hence, the number of vibrations in a given time must be inversely as the distance; and if we suppose the radius of the earth at the base of the mountain to be 4000 miles, the distance from the centre at the summit is 4001 miles. Therefore, for every 4001 beats at the base, there would be but 4000 at the summit. There are 86,400 seconds in 24 hours, and at this rate, the clock at the summit would lose 21.6 seconds every day. You can at once perceive to what an astonishing degree of accuracy we might arrive in determining heights and also in ascertaining the figure of the earth, or even the local attraction of mountains, by means of the pendulum, if we could rid it of all errors from the resistance of the air, the changes of temperature, and other causes. Most of these causes have been carefully studied, and rules have been laid down, or mechanical contrivances adopted for their correction. Every vibration adds to the amount of any existing error, until it attracts attention and becomes a subject of calculation; and as our experiments may be continued for months or years, the unerring motions of the heavenly bodies—those eternal, never sleeping registers of time—are always ready to correct our mistakes: thus it is not astonishing that the motions of the pendulum have shed and continue to shed a flood of light upon many questions in philosophy which, in former years, would have been held, even by the learned, as far beyond the grasp of human reason.

OF THE IMPACT OF BODIES.

277. When bodies act upon each other by striking together, they are said to *impinge* upon each other, and the act of striking is frequently called the *impact;* in which sense this word is synonymous with *collision.* According to Webster impact really means the impression made by a blow, and not the act of striking—we shall therefore employ the word collison in preference to impact when speaking of the mere act itself.

278. You have been informed that when bodies in a state of relative motion affect each other mechanically, the impact is always proportional to the momenta of the bodies (195).

Now, while the weight or mass of a moving body remains constant, the momentum varies as the velocity (174), and while velocity remains constant the momentum varies as the weight (194). Let us illustrate these facts.

279. If a cannon-ball weighing 12 pounds, moving with a velocity of 120 miles per hour, impinge upon the wall of a fort, and if another ball of 32 pounds, moving with a velocity of 45 miles per hour, strike the same wall with equal directness, the impact will be the same in each case; for, the weight 12 multiplied by the velocity 120, equals 1440, and the weight 32 multipled by the velocity 45 also equals 1440; hence the momenta of the two balls are the same in amount. Again: You may be unable to break a hard stone with a light hammer, because you cannot give it sufficient velocity to render its momentum superior in force to the cohesion of the stone; but with a heavy sledge, to which all your strength can give but moderate velocity, you readily effect the object, because the quantity of matter in the sledge acquires great momentum even with little velocity. The impact of moving bodies is not proportional to their actual, but to their relative velocities; hence the equality of action and reaction in all cases relating to the impact of bodies (174, 176). Therefore, as a body striking another is resisted to an extent equal to the force of the blow, it is obvious that *one body cannot check in another or communicate to another, any more relative motion than it loses itself.*

280. *Impact of inelastic bodies.**—Hence; when two inelastic bodies meet in collision, if the direction of their motion be opposite and their momenta equal, each will expend all its momentum in checking the other, and both will come to rest.

281. But if the opposite momenta be not equal, that body which has the less amount of moving force expends all that it possesses in checking an equal amount of the momentum of its antagonist, and the latter then employs the remainder of its power in giving velocity to the former, until the two bodies move forward with equal velocities, and thus lose their ability to act mechanically upon each other.

282. When bodies of different weight but equal velocities meet together, their momenta being proportional to their weights, the more powerful body must share its surplus momentum with the less powerful body in like proportion, and

* In the impact of elastic bodies other forces are called into play and modify the result, as will be presently explained.

the whole momentum of the two bodies after impact is equal to the difference of their momenta before impact.

283. If two inelastic bodies moving in the same direction with different velocities come into collision—the more rapid body overtaking that which is less rapid—the former will impart to the latter a portion of its momentum, and will continue to do so, being checked in its own velocity while it accelerates that of its antagonist, until both move forward with equal velocities and the momentum of the two bodies becomes distributed between them, as in the previous case, in the just proportion of their several weights: But here *the whole momentum of the two bodies after impact, is equal to the sum of their momenta before impact.*

284. If inelastic bodies moving obliquely towards each other come into collision, the same laws are equally applicable to their impact and its results; but in this case, the only portion of their motion interested in the collision, is that which tends to bring them directly together so as to act perpendicularly upon each other (219).

285. To illustrate these facts, let us take a few simple examples: Suppose that a rail-road car, which we will designate by the letter A, weighs 10 tons and has a velocity of 8 miles per hour, and that it meets another, which we will term B, weighing 15 tons, and moving in the opposite direction with a velocity of 4 miles per hour. The momentum of A will then be represented by $10 \times 8 = 80$, and that of B by $15 \times 4 = 60$. Here the momentum of A will entirely overcome that of B; but in doing so it must lose as much momentum as it has thus checked (279); that is, its momentum is reduced to $80 - 60 = 20$. A then struggles to go forward by means of this remaining momentum, but in this effort it is constantly and equally opposed by the resistance of B, and, for every impulse by which it drives B backward in consequence of its superior momentum, it must lose an equal amount of its own impulsive force, until the surplus momentum is divided between the two cars in just proportion to their respective weights. Then, indeed, the surplus momentum becomes available in carrying forward both bodies together in the direction of motion of the more powerful body A. But this surplus momentum which previously gave velocity to only 10 tons—the weight of A—has now to give velocity to 25 tons,—that being the weight of the two cars: After the collision, then, we shall have 25 tons moving with a momentum of 20. But as the momentum of any moving body is represented by the velocity multiplied by the weight, the ve-

locity will be represented by the momentum divided by the weight: therefore the velocity of the two cars just mentioned, when moving together after the collision, will be $\frac{25}{25}=1$ one mile per hour.

286. Let us suppose A to overtake and impinge upon B when travelling more rapidly in the same direction, the several velocities and weights of the cars remaining the same. A will then impinge upon B with a relative velocity of 4 miles per hour, and its relative momentum will be represented by $10\times4=40$. After collision this force is diffused through 25 tons of matter, and its effect upon the motion of the two bodies after collision will be represented by $\frac{40}{25}$. The velocity of the two bodies when moving uniformly together after the collision will therefore be more rapid than the previous motion of B by $\frac{40}{25}$ or 1 mile and $\frac{3}{5}$ of a mile: that is: the joint velocity of the cars will be $5\frac{3}{5}$ miles per hour: and this velocity, multiplied by the weight of the two cars in tons, 25, will be found exactly equal to the sum of the momenta of the two cars before contact.

287. From these examples we may deduce the following rules for calculating the velocities of inelastic bodies after collision, when the velocities before collision are known and both bodies are free to move.

(*a*) If the bodies be moving in opposite directions, divide the difference of their momenta by the sum of their weights or quantities of matter, and the quotient will be the joint velocity after impact, which will be in the direction of the greater momentum.

(*b*) If the bodies be both moving in the same direction, or if one of them be at rest, divide the whole momentum of both bodies conjointly, by the weight of both bodies conjointly, and the quotient will be the joint velocity after impact, in the same direction with the previous motion.

288. Suppose an inelastic ball of two pounds weight to come in contact with another such ball weighing one pound, and let the direction and velocities of the two balls at the moment of contact be represented by the lines B A and C A, Fig. 108, respectively. Also; let E G represent the tangent to the two surfaces at the point of contact, and L M a line perpendicular to the tangent at that point: then only those por-

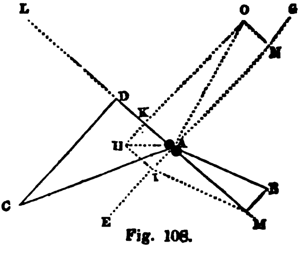

Fig. 108.

tions of the momenta of the two bodies which act in the direction of the line L M are interested in the impact (284). Draw B M and C D perpendicular to L M and complete the parallelogram B A I M. Then M A will represent that portion of the velocity of the two pound ball that acts in the direction M L, and D A will represent the portion of the velocity of the one pound ball which acts in the opposite direction L M. The remaining velocities in the directions B M and C D, being parallel to the tangent at the point of contact, will continue unchanged after collision and may be left out of our calculation for the present. For the sake of the illustration we will suppose that the two pound ball is approaching the tangent G E with a velocity of 20 miles per hour, while the one pound ball approaches it at the rate of 15 miles per hour—M A will then represent twenty miles and D A fifteen miles. Multiply these quantities by the weights of the respective balls and we find the momentum of the former to be 40 and that of the latter 15. Now, (287, *a*) by dividing the difference of these opposing momenta$=25$ by the sum of the quantity of matter in the two balls as measured by their weight$=3$, we obtain the joint velocity of both bodies after collision in the direction of the more powerful momentum, A L, to be $8\frac{1}{3}$ miles per hour. Take $8\frac{1}{3}$ from the same scale of equal parts by which the figure has been constructed, and lay it off from A to K. A K will then represent what would be the direction and velocity of the two bodies after collision, were there no other force acting upon them at the same time. But the two pound ball has not lost that portion of its velocity represented by B M or A I; and it must therefore move after the contact under the influence of both the velocities A K, which results from the collision, and A I which remains unaltered from its former condition. Complete, under these velocities, the parallelogram A I K H, and the resultant diagonal A H will represent the true velocity and direction of the ball of two pounds. In like manner, the ball of one pound retains the velocity C D even after acquiring the velocity A K by the effect of collision. From the point of contact and along the tangent A E, lay off A N, equal to C D. The ball of one pound will move after collision with both the velocities A K and A N: compound them by completing a parallelogram upon them, and the resultant diagonal A O will represent the true extent and direction of the velocity of this ball after collision.

289. When one hard elastic body impinges upon another

of the same character which cannot be moved perceptibly from its position by the blow, such as a wall or a rock, the effect may be readily estimated simply by the resolution of forces.

290. *Modifications of impact by the peculiar properties of bodies.*—Many modifications of the apparent effects of collision are produced by the special or peculiar properties of bodies. A pistol-ball fired at a pane of glass suspended by a long cord, penetrates it without communicating any considerable velocity to the remainder of the pane, or to the fragments that are not in the direct range of the ball; because time is not allowed for the communication of motion to them; but if it be shot into a loaf of bread suspended in similar manner, it does not pass entirely through the loaf, and consequently its momentum becomes equally diffused through the whole mass.

291. When a soft body impinges upon any hard surface, the molecules first checked in their motion still act and react

Fig. 109.

upon those in their rear, which struggle to get forward; and—the whole mass moving like a collection of pebbles—the particles are scattered in all directions by collisions among themselves; yet each particle obeys the laws of impact as already explained in this paragraph, whatever new forces may be brought to bear upon it in the general contest: Thus; when a wet snow-ball is thrown obliquely against a wall, the fragments, instead of sliding uniformly along the surface in the route of the undestroyed portion of the original motion, are found adhering in every direction around the point of contact. But, though the particles in this case are equally pressed outwards from a common centre by the reaction of the wall, those lying on the side towards which the original

motion tends are thrown to a considerable distance by the undestroyed portion of their momentum, while those next the side *from* which the original motion tends, having their previous momentum almost overcome by the reaction of other particles in their rear, move but a short distance and with a feeble velocity, and if this scattering force be sufficiently great, their velocity may be in the retrograde direction. The mark made on the wall by the snow-ball therefore takes somewhat the form represented in Fig. 109. When a soft body impinges upon anything smaller than itself, the force exerted cannot exceed the momentum of that part of the mass which actually strikes the object, added to the force necessary to overcome the cohesion between that portion and the remainder of the soft impinging body. Thus; the masses of snow that fall during a thaw from the roofs of houses may be dangerous to life or limb; but, were they to impinge upon the human frame with the momentum of the entire masses—like hard or strongly cohesive bodies—they would scarcely leave a trace of the humanity of their victims.

292. Many seemingly wonderful feats of strength cease to astonish when we are aware that the momentum of impinging bodies becomes equally distributed through the whole mass of matter, so as to diminish the velocity in proportion to the weight. Let A, Fig. 110, represent a lad weighing 120 pounds, and B another lad weighing 100 pounds. If these lads clasp hands and properly apply their strength, A can drag B from place to place at will; for, by his muscular efforts and the aid of gravity when leaning in any direction, he can exert more momentum with a jerk than his antagonist can suddenly check by a similar exertion. But, for the same reason, if B permit a third lad C, to mount his shoulders, though seemingly charged with an additional labour, he can easily compel A to follow him in all his wanderings.

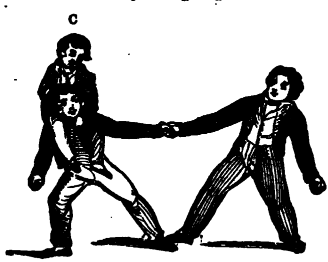

Fig. 110.

293. A strong man resting on two chairs, in the attitude represented in Fig. 111, can readily support an anvil weighing 60 pounds, when placed upon the middle of the body; and a bar of heated iron may be forged upon

this anvil without calling for much greater exertion on the part of the performer: For; if the hammer weigh four pounds, and if it be moved with a velocity of 16 feet per second in striking the blows, its momentum will be 64; but after collision, this momentum will be equally distributed through the 64 pounds of matter contained in the hammer and anvil, and the velocity after collision will therefore be but one foot per second; which motion is so slow as to be readily overcome by the resistance of the body, yielding to the force for a time, so as to destroy the momentum very gradually.

Fig. 111.

294. When inelastic malleable bodies impinge upon each other, or, upon a hard surface, they are usually flattened by the blow, and sometimes exhibit very curious proofs of the reaction of their particles. Fig. 112 represents, in profile and front view, the appearance of a musket-ball picked up on the field of Waterloo, after it had struck and fallen from a garden wall. The part which impinged directly upon the stone, was slightly flattened, but preserved almost perfectly its spherical form, by the power of the arch: the opposite portion—that farthest removed from the point of contact—presented the same figure still more remarkably; but the whole middle portion, checked by the arrest of the particles next the wall, and still pressed upon by those in the rear, was squeezed out into the broad fan-shaped expansion seen in the figure.

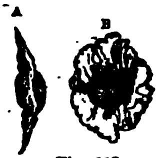

Fig. 112.

295. *Impact of elastic bodies.*—Of course, the ball just mentioned had expended all its momentum upon the wall, before it fell to the ground; but let us suppose that the flattened and displaced particles had possessed the power of instantaneously resuming their places by their mutual attraction, so as to restore the proper figure of the bullet after the compression. It is obvious that in so doing they would force themselves to a greater distance from the wall, and would react upon the surface with a force proportional to the quickness of this motion. Thus they would acquire a new and opposite momentum which would cause the ball to rebound to a considerable distance. To prove this fact experi-

ally, procure a hoop of hickory or metal, and after pressing it into an oval form against the ground, set it suddenly at liberty. It will instantly spring into the air by reacting upon the surface against which it is pressed. Now; this is a peculiar result of the property of *elasticity*, which very materially influences the effects of the collision of elastic bodies.

296. Glass, ivory and marble furnish fine examples of elasticity. When pressed out of shape they recover their form so quickly that the change is often imperceptible to the eye. If you gently lay a billiard-ball or a playing marble upon a very hard table coloured with red chalk, a mere dot will mark the place of contact; but if it be allowed to fall from a height, it immediately rebounds, and the dot is found to be expanded into a considerable circle, proving that the ball has been momentarily flattened by the blow, but has as instantly recovered its former shape by its elasticity.

297. Now; in this case, the ball is brought to rest at the moment that the flattening is greatest: all its momentum in the direction of the table is then lost; and when it again rises into the air, its momentum in the upward direction is not the immediate effect of the collision, but is caused by the force with which the body recovers its figure and the resistance of the table to the motion of the particles in the act of resuming their position. Here it is obvious that the ball could not leap from the table without striking it a blow after the downward momentum is lost, and this blow must be sufficiently hard to account for the height to which the body springs. If the resistance of the air be removed by the air-pump, it is found that ivory will bounce almost to the height from which it falls, and it would mount quite to that height were it absolutely perfect in its elasticity. This clearly proves that the blow struck by the ball in rebounding is as hard as that which it strikes in falling. But both these blows take effect at the moment of impact: Therefore, in the collisions of elastic bodies, the impact is just twice as great as it is in the collisions of inelastic bodies. Let us examine the consequences of this law.

298. If an inelastic body impinge upon another inelastic body of equal weight and in a state of rest, the two bodies will proceed together after impact with half the previous velocity of the moving body (281). But if the bodies be both elastic, the action of the one and the reaction of the other are both doubled by the elasticity: the moving body will therefore communicate just twice as much momentum

to the body at rest, and will itself lose just twice as much motion as in the case of the inelastic bodies. But, in the former case, the one body loses and the other gains one half the momentum of the moving body; consequently, in the latter instance, the moving body will lose all its momentum and will come to rest, while the body at rest will acquire all the momentum, and will proceed after impact with the previous velocity of the impinging body.

299. A neat apparatus for experiments on elasticity is represented in Figs. 113 and 114. It is composed of a number of ivory balls, A, B, C, D, E, F, G, Fig. 114, suspended upon silk cords from a row of pins, I, on a perpendicular board. When at rest, these balls are in contact throughout the series. Let all the balls, but two, A and B, Fig. 113, be removed from this apparatus. Then raise the ball A to *a*, and allow it to fall upon B. By the law laid down in the last paragraph, A will communicate all its momentum to B, and the former will come to rest while the latter flies onward to *b*. This ball, returning again, impinges upon A with scarcely diminished force, and A is thus again nearly driven to *a*: thus the two balls continue to vibrate for some time, like a pendulum, each confining its motion to its own half of the arc.

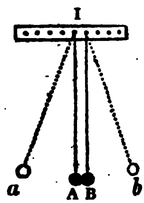

Fig. 113.

300. When an elastic body strikes upon a hard immoveable substance which will not yield to compression, the rebound is as great as when it impinges upon another elastic body; and this fact is thus explained:—When an elastic body strikes a hard, inelastic, immoveable substance, its whole force is rendered effective in compressing itself, and it recovers its shape with its whole force: but when it is impelled against another elastic substance, part of its force is expended in compressing this substance, and only the remaining portion is available in changing its own form; therefore, when such bodies are driven asunder by their elasticity after the impact, each furnishes its share of the separating force; but the total is no greater than the single force in the former case.

301. If a soft, inelastic substance, such as putty or clay, be substituted for the ball B, in the last experiment, the momentum acquired by A in falling is overcome slowly, and the ivory not being much compressed, the effect of elasticity is lost, and the two bodies move together after impact nearly as if both were inelastic.

302. If the two balls A and B, Fig. 113 be drawn asunder to a and b, and there set free at the same moment, they will meet in the middle of their course, and each will transfer its whole momentum, or,—as the weights are equal—its velocity to the other; therefore each ball will rebound to the height from which it fell. If the balls be allowed to fall from different heights, they will acquire different velocities, but will still meet very nearly in the lowest point of their arcs, by a law of the circular pendulum (267). Let us suppose that A reaches this point with a velocity equal to 2, and B with a velocity equal to 3. After impact these velocities will be interchanged, and A will rebound with the velocity 3, and B with the velocity 2: Thus, they will continue vibrating through longer and shorter arcs, alternately and interchangeably. This may perhaps be rendered clearer by an explanation:—The sum of the momenta of these balls, which, in this case, is 5, is equal to the entire force with which they come together; and this is doubled by the force of elasticity (297): The whole effect of the blow is therefore represented by 10. But as action and reaction are always equal, this force is evenly distributed between the two balls, which, being equal in weight, one half, or 5 parts, of the force is effective upon each ball. Now; of the 5 parts appropriated to A, 2 parts are destroyed in overcoming its previous velocity, and the remaining 3 parts determine the rapidity of its rebound, while, of the 5 parts appropriated to B, 3 are destroyed in overcoming the previous velocity, and only two parts remain to determine the rapidity of the rebound. Thus the bodies must interchange velocities at every vibration.

303. If, in the entire series, represented in Fig. 114, the ball A be raised to H and then allowed to fall upon B, the latter will receive all the momentum of the former, and will endeavour to move off with equal velocity, while A will be brought to rest by the reaction of B; but the moment that B attempts to move, it impinges upon C, to which it communicates the same momentum, and is also brought to rest by the reaction of C. In fact B receives two equal blows in opposite directions at the same moment; one from the direct action of A, and the other from the reaction of C. The momentum being thus trans-

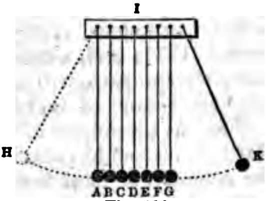

Fig. 114.

mitted to C, the latter communicates it in the same manner to D, and thus it passes onward to E and F, without producing any visible motion, if the elasticity be perfect. But when the momentum is communicated to the last ball of the series, G, there remains nothing to oppose its motion, and it therefore rises to K with the same velocity and force with which A at first impinges upon B. Thus, the two extremes of the series alternately act and react upon each other through the medium of the intervening matter, as if they came directly into contact in the manner described in the two preceding paragraphs.

304. In the series represented in Fig. 114, if the two balls A and B be raised and allowed to fall together, the two balls F and G will fly off together from the other end of the series; because the momentum of both balls being communicated, through C, D and E, to F and G, one half this momentum is sufficient to communicate a full share of velocity to G, and the remaining portion is employed in giving an equal velocity to F. For similar reasons, if more balls be raised, an equal number will fly off in consequence of the collision. Thus; if A, B, C, D, E, and F be raised together and suffered to impinge upon the single remaining ball G, an equal number,—that is; all but the first ball, A,—will fly off in the direction of K; and when these balls return, the effect is reversed; G remaining at rest while all the others are projected in the direction of H; thus six balls are always vibrating, while the extremes of the series are alternately left in a state of repose.

305. If a sphere, composed of any soft, inelastic substance, be substituted for either of the elastic balls in the series, Fig. 114, we shall find, on repeating our experiments, that the peculiar effects of elasticity will be in great degree destroyed, because the momentum of the impinging bodies will be overcome slowly by the resistance of the inelastic matter (178); and, consequently, the motions of the several balls, after impact, will resemble pretty nearly those observed after the impact of inelastic bodies.

306. As the impact of bodies is doubled by the property of elasticity, it requires considerably less momentum to overcome the cohesion of hard bodies when endowed with this property; they therefore yield with comparative readiness to blows of moderate strength. This fact assists in explaining the connexion often observed between elasticity and frangibility (151, 152).

307. Solid bone is nearly as elastic as ivory; and if the

bones of the human body were equally solid throughout and in contact with each other, every jar received upon the feet would be transmitted to the head with undiminished energy; every sudden misstep would disorder the brain like the blow of a bludgeon; and in falls or leaps from considerable heights, if the skull were not crushed by the momentum transmitted from the other bones, the elastic force would almost cause it to fly off from the shoulders, like the last ball of the series in one of the foregoing experiments (303). But the most elastic portions of the human skeleton are separated at the joints by the interposition of soft and imperfectly elastic cushions of cartilage, which render the transmission of forces from one part to another slow and gradual. Nor is this our only protection. Fig. 115 represents a section of one of the principal long bones

Fig. 115.

of man. The white and outside part of the middle portion, *b*, *b*, is solid and highly elastic, but this solid portion becomes a mere shell or film as it approaches the extremities, and the central portions of the shaft, together with nearly the whole of the extremities which form the joints, are occupied by a spongy net-work of flexible bony plates or fibres embedded in soft marrow and possessing very little elasticity. The spinal column, or, as it is commonly styled, the back bone, is composed of no less than twenty-four pieces, each formed of a loose spongy substance filled with marrow, and separated by cartilage; hence the force of blows on the feet is communicated to the head with considerable difficulty: But, for a more enlarged view of this interesting subject in animal mechanics, we must refer you to the "Physiology for Schools."

308. *Reflection of elastic bodies.*—There is one circumstance attending the collision of elastic bodies which deserves especial notice, because it explains one of the most important laws of nature, to which frequent reference will be made hereafter. *When an elastic body impinges upon an immoveable and incompressible body, the angle of reflection is always equal to the angle of incidence.* Let E F, Fig. 116, represent the surface of a smooth, level, hard or elastic and immoveable body; and let A B represent the direction

of an elastic body approaching the plane, to impinge upon it at B. Draw the line B D perpendicular to the plane. Then the body will rebound, after the collision, in the direction B C, making the angle of reflection, D B C, equal to the angle of incidence, A B D. Join A D and D C by a line drawn parallel to E F, and let the entire velocity of the moving body be represented by the line A B: Then, by the resolution of forces, the line D B represents the velocity with which the body approaches towards the plane, while the distance A D or D C represents the velocity of its motion in a direction parallel to the plane: Not only is the former velocity D B destroyed by the collision, but a new, opposite, and equal velocity is generated by the elastic force which if allowed to act alone, would carry the body back in the direction B D, to the same distance through which it approaches the plane, and in the same time (297): But, as this action in the perpendicular direction does not interfere with the motion parallel to the plane, represented by D C, the body, after impact, will describe the line B C under these combined forces, in the same time that would be required to carry it to D by the force of elasticity alone.

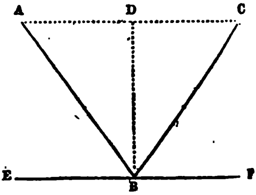

Fig. 116.

309. It is unnecessary to enlarge upon the effects of impact in changing the velocities and direction of motion in elastic bodies, as all these results are readily explained by the rules already laid down. Thus; when two elastic bodies come in contact obliquely—those portions of the momenta which take effect in the perpendicular direction being alone interested in the collision, while the remaining portions continue unchecked in quantity and unchanged in direction—if one of the bodies be at rest, the other transfers to it all that portion of its momentum which acts perpendicularly, and comes to rest in that direction, like the ball A in the experiment described in paragraph 299, while it continues to move in the direction of a tangent at the point of contact, as if no collision had taken place. If both the bodies be in motion obliquely towards each other, they interchange the momenta with which they come directly in collision, as in the experiment narrated in paragraph (302), without altering in the slightest degree the remaining portions of their momenta. These facts, with the rules laid down for the reso-

lation of compound forces, will enable you to calculate the results of the simple impact of elastic bodies in all cases, and the action of the little balls in the childish game of marbles will give an abundance of practical illustrations.

OF EQUILIBRIUM AND THE CENTRE OF GRAVITY.

310. If a body be suspended freely at the extremity of a cord, it will be drawn towards the earth in the direction of gravity, and will hang like a pendulum at rest. The position of the body while thus at rest will be regulated by its form and by the manner in which it is suspended: thus; let A B D, Fig. 117, represent a parallelopipedon suspended horizontally upon the cord E G. Each atom in this block being attracted towards the earth with the same degree of force, and the atoms on opposite sides of the line G E being arranged in exactly similar order, every single atom towards one end of the block is exactly balanced by another atom, similarly situated towards the other end, and the whole of one end of the block must exactly balance the other. For similar reasons, the whole of one side of the block must exactly balance the other. If we now elevate any portion of this block we bring an additional quantity of matter towards that side of the line of suspension, and thus increase the force of gravity acting upon that side without any corresponding increase on the opposite side. Thus, the balance or *equilibrium* of the block is destroyed, and when left at liberty it vibrates like a pendulum until brought to rest by the resistance of the air in its original position. Here, then, the body A B D is exactly balanced because gravity acts with equal force upon all sides of the line E G. Now; let the block be detached and again suspended by means of a hook C, inserted at the middle point of one extremity. The force of gravity will then bring it to rest in a new position; for instead of continuing to hang horizontally, it will assume a perpendicular position, and the dotted line C F will correspond with the line of suspension: Here, as before, gravity acts with equal force upon all sides of the line C F and the block is once more exactly balanced. But the line C F must cross or intersect the line E G at some fixed point; for, if it passed on either side of E G, the force of gravity acting upon each side of E G could

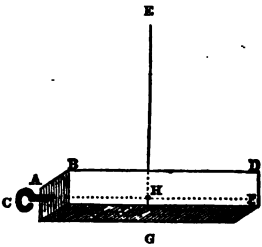

Fig. 117.

not be balanced as has been proved to be the case. Now let the point of intersection of these two lines be at H. The same mode of reasoning will show that if we were to choose any number of points of suspension on the surface of A B D, allowing the body to come to rest after each experiment, the line of support in each case must pass through the same point H. Hence gravity must act with equal force upon all sides of this point, whatever the attitude of the body may be, and if H be supported in any manner,—by cord, prop, attraction or centrifugal force—the body will remain balanced and at rest in any attitude, unless disturbed by other forces. Gravity therefore acts upon the whole mass as if all its matter were concentrated upon this point, which is therefore called *the centre of gravity.*

311. There is a point within every body, however irregular in form, around which all the matter contained in it will balance itself in every position of the body. Thus; if a rude rock A E B D be suspended by a ring at A, it will come to rest about some line of suspension A B, and if again suspended from any other point E, it will again come to rest about another line of suspension E D. The point C, where these two lines intersect each other, is therefore the centre of gravity of the rock, about which, if supported, it will remain at rest in any attitude. This mode of double suspension often furnishes us with the most convenient mode of determining by experiment, the position of the centre of gravity in small, irregular bodies.

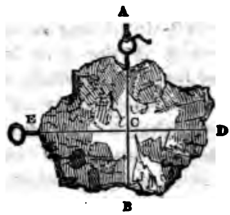

Fig. 118.

312. From the foregoing facts we may deduce two practical conclusions which should be treasured in the memory:

(*a*) All lines drawn in the direction of gravity from the point of suspension of a suspended body, must pass through the centre of gravity.

(*b*) When a suspended body is left free to change its position, the centre of gravity will seek the lowest possible position; which is directly under the centre of suspension.

313. If a body be supported by a prop instead of the cord of suspension, it will remain at rest only when the support is placed exactly under the centre of gravity. Thus, if the block A B D, Fig. 117, be made to rest upon the point of a needle placed exactly at G, it will preserve its equilibrium, because the centre of gravity H is directly above that point; but if

needle be placed at any other spot on the under surface, nearer to either side or extremity, the opposite side or extremity will preponderate and the centre of gravity will descend until the block slides from the support. It is only while the block preserves its attitude exactly, that the needle can give it any permanent support; for the instant you depress either extremity of the body, the centre of gravity revolves a little in that direction, and being no longer immediately above the point of support, continues to descend until the whole block falls as before. Fig. 119 represents this block placed in an oblique direction upon a pointed stand C. It is evident that in

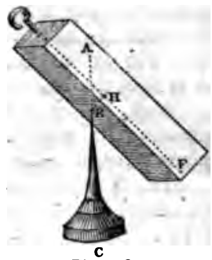

Fig. 119.

this attitude it cannot remain at rest; for, the line of support is in the direction E A, while by far the heavier mass of matter, and consequently, the centre of gravity H, lie between that line and the extremity F.

314. Rocks of enormous weight so feebly supported that the force of a single man may move them, are occasionally found upon the summits of lofty precipices. These great bodies are placed in situations nearly resembling that of the block balanced upon the needle.

315. The position of a gravitating body resting upon a surface, is *stable* or *permanent* only when the perpendicular line dropped from its centre of gravity falls within the base upon which it rests. C D, Fig. 120, represents a horizontal plane upon which works another inclined plane C E or C F, by means of a hinge at C. Upon the latter plane place two rectangular blocks of wood in the position and of the shape represented in the figure, and let the central black dot represent the situation of the centre of gravity in each block. From these dots to the points A and B on the plane let fall perpendicular lines to represent the direction of the force of gravity. When the upper extremity of this plane is elevated to E, the points A and B will both be found considerably within the bases of the respective blocks; consequently, the centres of gravity will be supported by the plane and both bodies will remain upright. Let us then elevate the plane nearly to F. At a certain elevation, the perpendicular falling to B will be found to terminate exactly at the lower edge of the upper block, which will then be balanced as nicely on that edge as if it were supported on the edge of a penknife:

the least force would overturn it. Raise the plane completely to F, and the perpendicular to B will fall on the outside of the base, the centre of gravity will be no longer supported, and the body must immediately roll over towards C. Yet we still find the point A within the base of the smaller block, which will therefore preserve its position, and the plane must be raised still higher before it can be overturned.

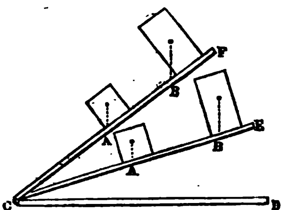

Fig. 120.

316. A gentleman walking in Chesnut street or Broadway, elevates his head, throws his shoulders backward, and his chest forward, giving his form the greatest development possible with all the aid his tailor can bestow, while he points his toes outwards, treads the ground with the walking-step of the dancer, and directs his shoemaker to trim down the high heels of his boots nearly to a point and bring the narrow sole as close as possible to the demonstration of a mathematical line, as if to prove upon how slender a foundation the reputation of a lofty character may be supported. The smooth, hard surface of the promenade secures him from all danger of finding the direction of gravity falling without the base. The skater goes farther, and fearlessly assumes positions not to be maintained for an instant without the aid of the centrifugal force to counteract attraction. But the sailor, perpetually tossing on the waves of the sea, preserves his equilibrium by parting his bare or lightly clad feet widely, and places one somewhat in advance of the other, with his toes pointing directly forward or a little inward, to give himself the advantage of the broadest base; while his large trousers, his slightly bent and supple knees, his stooping and depressed shoulders, fore-shortened neck, head crouching upon the chest, light jacket and low-crowned tarpauline, all seem expressly designed to bring the centre of gravity to the lowest point consistent with the free use of his unembarrassed limbs, and the cat-like activity essential in his dangerous profession.

317. If all the heaviest articles in the wagon Fig. 121 be stowed as low as possible, so as to bring the centre of gravity to A, the direction of the line of support pointed out by the plummet line A B shows that the vehicle would be perfectly safe upon the road: But if an unskilful person should place the lighter articles below and the heavier goods above them, so as to raise the centre of gravity to C, the plummet line C D

that this centre is scarcely supported; for the line of falls upon the rim of the lower wheel, and conse- the slightest softness of the ide of the road would suffice turn the wagon. So, when riest part of the cargo is placed ar the keel of a vessel, the f gravity being very low, the aintains her upright position reat obstinacy. Even if n on her beam ends," she or "right herself" again, if o be not shifted, the moment wind ceases to act upon her

Fig. 121.

lence: but a ship thus loaded "recovers" again so that the masts may be whipped off by the jerk, as wand will break in the hand when moved or checked kly. On the other hand, if the centre of gravity l too high, the vessel rolls and pitches to a danger- nt. Few nautical duties require more judgment than er stowage of a cargo.

When a round ball of equal weight in every part is n an inclined plane, the perpendicular dropped from re of gravity must always fall without the base, and ently, the ball will roll down the plane, whatever be ation. The centre of gravity in all regular solids is lle point of the space which they occupy, and that phere is therefore its ge- l centre. Let A, Fig. a light round ball of uni- eight throughout, placed inclined plane similar represented in Fig. 120. , the centre of gravity of ere, draw C D, perpen- o the plane at the point

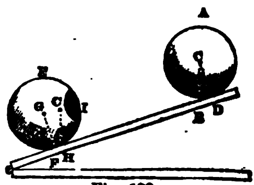

Fig. 122.

becomes a tangent to the ball, and draw also C B in ction of gravity. The base, in this case, is the point the perpendicular line C B dropped from the centre ty falls entirely without that base: the ball must e roll down the plane. But suppose another similar o be loaded by the insertion of a mass of heavier mat- : the centre of gravity, C, will then be removed from *metrical centre*, or centre of the figure, G, and nearer to the weight I. From the geometrical

centre, draw the line G F, perpendicular to the plane, and the point F will represent the base on which the ball stands; draw also the perpendicular line C H in the direction of gravity, and it will fall without the base towards the upper end of the plane. Here the centre of gravity not being supported, must descend, but it can only do so by causing the ball to roll *up the plane* till the weight I reaches the surface and the point C coincides with the line G F. In this apparent paradox it is only the figure of the sphere that ascends the plane, while its matter is actually falling; for gravity acts upon the whole of a mass exactly in the manner in which it would act if all the matter in that mass were concentrated in the centre of gravity, and in the case before us, that centre, C, descends towards the plane.

319. For many purposes in the arts it is desirable to bring the centre of gravity below the point of support; and in this way stability is given to bodies where you would not at first sight suppose that the principle was that of simple suspension. In Fig. 123, A B represents a loose board slightly overlapping the edge of a table, D. Were this board unsupported, it would fall: yet, if a heavy weight W be suspended to its free portion, and if this weight be retained at a considerable distance beneath the edge of the table by means of a long rod bearing against a check placed beneath the board at E, the whole apparatus will remain stable, because the weight W brings the centre of gravity of the apparatus so near to itself that the perpendicular line passing through that centre, when continued upwards, falls within the edge of the table, and the centre is therefore directly supported by suspension. If the long rod were securely and permanently fastened to the board at E, the rope attached to the weight might be cut away without disturbing the equilibrium of the board, which would thus be kept from falling by hanging a weight to its free extremity. On this principle safe bridges may be thrown over otherwise impassible ravines.

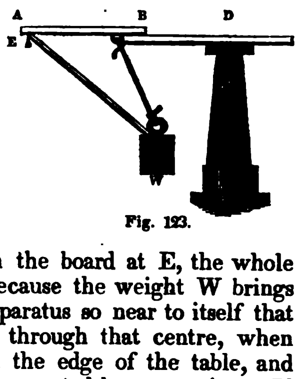

Fig. 123.

320. Many of the feats of rope dancers and other balancers appear much more difficult than they really are. By carrying a long, light pole, heavily loaded at each end, a performer possesses the power of raising, depressing and changing the *centre of* gravity to a great extent at will, and thus pre-

ve their equilibrium. By means of firm nerves and such pole, a man may cross a torrent upon an ordinary rope with perfect safety.

321. If two balls of equal weight, A and B, Fig. 124, be connected together by an inflexible rod of equal thickness in every part, or if we suppose the connexion to be made by means of a rod altogether without weight, these balls will balance each other exactly when the rod, being placed horizontally, is supported at its middle point, C: for; the two balls being similarly situated in all respects, neither of them could move under any force without compelling the other to move in the opposite direction to the same extent:—that is; each must acquire the same momentum, which requires for its production the same amount of force: but though, of two equal and opposite forces, one may balance or neutralize the other—neither can ever overcome the other: and hence neither body can move from its position.

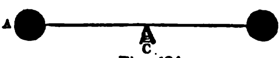

Fig. 124.

322. But if, in a similar *system* of two bodies and a rod, one of the bodies be heavier than the other, they will no longer balance each other when the middle of the rod is supported; for the greater weight brings the centre of gravity of the whole instrument nearer to itself, and until that centre is supported, there can be no stability in the system. Let Fig. 125 represent such a system, in which A is the heavier and B the lighter body. Let the support H, be moved along the rod from the middle point, until it comes directly under G, the centre of gravity of the system. The whole will then be upheld when in the horizontal position, and both bodies will remain at rest. It appears strange to beginners that so small a body as B should be able to balance so large a one as A, merely because it is placed farther off from the prop upon which the system reposes, though it is evident that the force of gravity acts upon the larger body with far greater force. It is all-important that you should clearly understand the reason of this balance, because it furnishes the simplest instance of what is called *an action with mechanical advantage*.

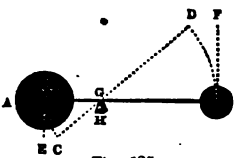

Fig. 125.

323. The circumferences of different circles are proportional to their diameters, and therefore to their radii. Hence, similar arcs in different circles must be also proportional to

the radii. Now, in Fig. 125, if the great ball A which is attracted towards the earth in the direction A E, should move at all, it must describe an arc A C. But it cannot do so unless the lesser ball B at the other end of the inflexible rod should describe a corresponding arc B D in the same time and manner. But the arc B D is as much greater than the arc A C, as the radius G B is greater than the radius G A—that is $BD : AC :: GB : GA$. Now, the distances described by moving bodies in the same given time are measures of the velocities of those bodies: therefore, if the ball A should move at all, its velocity will be represented by A C, and that of the ball B by B D. But the velocity of a body multiplied by its weight, mass or quantity of matter, represents its momentum or moving force. Therefore the weight of $B \times BD$ represents the momentum of B, and the weight of $A \times AC$ represents that of A. But as $BD : AC :: GB : GA$, we may take the two latter proportionals instead of the two former, and by multiplying them by the respective weights of B and A, we shall obtain two numbers exactly proportional to the momenta of these bodies, and we may therefore employ these numbers to express the relative momenta of the weights. Thus; if the weight of $B \times GB$ be taken to represent the momentum of B, then the weight of $A \times GA$ will represent the momentum of A: and these momenta act in opposite directions. These two forces therefore tend to check or neutralize each other. Now suppose that $B \times GB$ is equal to $A \times GA$—that is, suppose that B multiplied by its distance from the centre of gravity G, is equal to A multiplied by its distance from the centre of gravity—it is evident that the momenta of the two balls being equal and opposite, if they be moved by gravity or any other force, the one will instantly counterbalance the other: *Therefore they cannot move at all.*

324. If the support or prop H were placed nearer to A, $B \times BH$ would be greater than $A \times AH$, and by virtue of its increased relative momentum when put in motion, it would enjoy a mechanical advantage over A; and by descending would cause it to rise: but if the prop were moved nearer to B, $A \times AH$ would become greater than $B \times BH$, and the ball A would subside, forcing B to ascend.

325. As gravity acts upon all bodies precisely as if their masses were concentrated in their centres of gravity, it is necessary in calculating the effects and the reactions of bodies placed at different distances from the centre of gravity of a system, that we should estimate those distances by measuring,

not from the exterior surface, but from the centres of gravity of the bodies to that of the system: thus; the distance A G, in Fig. 125, must be taken, not from the outside of the sphere, but from its centre. This should never be forgotten.

326. As the momentum or effect of any weight in such a system as that just described must increase in exact proportion to its distance from the centre of gravity of the system, it follows that in order to obtain an equilibrium, the weights must be inversely, or as it is termed, *reciprocally* proportional to their distances. Therefore, in Fig. 125, B : A :: A G : B G. Hence; if we take the line B G to represent the relative weight of A, then A G will represent the relative weight of B; and consequently, the whole line A B will represent the relative amount of the sum of the weights. From this fact we may derive the following rules for calculating the weights and distances under various circumstances. But let it be remembered that, for the present, the effect of the weight of the connecting rod, though an important item, is neglected. It will be taken into consideration hereafter.

327. The weights and the length of the rod being known, it is required to find the centre of gravity:

(*a.*) As the sum of the weights A and B, Fig. 125, is to either weight, (B for instance,) so is the whole distance (A B) to the distance between the centre of gravity and the other weight (A G). Deduct this from the whole line (A B), and the remainder will be the distance of the other weight (BG) from the same centre. Thus; two boys, A and B, Fig. 126, wish to play at see-saw on a board 15 feet long, and wish to know how to fix the board — neglecting its weight—so that they may sit at the opposite ends and balance each other. A weighs 60 pounds, while B weighs but 42 pounds. They proceed with their calculation thus:

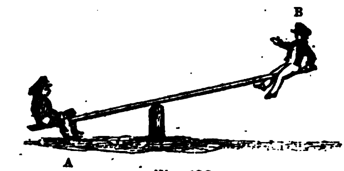

Fig. 126.

Sum of weight.		Weight of A.		Length of Board.		Dist. of B from centre.
As 102	:	60	: :	15	:	8 ft. 1 in. nearly.

Deduct this from the whole length of the board, and there remains 6 feet 11 inches, which is the distance from the centre of gravity to the place which A should occupy.

328. Both weights, and the distance of one of them from the centre of gravity being given, it is required to ascertain the distance of the other weight from that centre.

(*b.*) As the weight whose distance is unknown is to the weight whose distance is known, so is the distance of the latter to the distance of the former. For, in Fig. 125, let the weight of A and B be known, and also the distance A G. You have already been shown that B : A :: A G : B G. Thus B G is easily calculated.

329. The length of the rod, the position of the centre of gravity, and the sum of the weights being known, the amount of each weight is required.

(*c.*) As the whole length of the rod is to the distance of either weight from the centre of gravity, so is the sum of the weights to the other weight.

330. It is evident from the tenor of the preceding paragraphs that the effect of any body balanced upon a horizontal rod and acted upon by gravity, may be represented by the product resulting from multiplying its weight by the distance between its proper centre of gravity and the point of support. If, then, a number of bodies be ranged along the same rod on opposite sides of the support, as in Fig. 127, they will only be in equilibrium when $A \times A\,G + B \times B\,G + C \times C\,G = D \times D\,G + E \times E\,G + F \times F\,G$. Now, suppose that the little bodies in this figure be diffused along the cord instead of being concentrated into small spheres. They will then form a rod or bar of considerable weight; and this bar can only be in equilibrium when the sum of the products of each particle or atom of matter on one side of the support multiplied by its distance from this point, is equal to the sum of the products of each particle or atom on the other side multiplied by its distance from the same point.

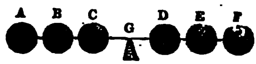

Fig. 127.

331. In the common scale beam, Fig. 128, this is always the case, for the two arms, A C, B C, being similar, the centre of gravity, D, is exactly in the middle of the beam, and the point of support, C, is placed as near to the same spot as may be convenient. It would not answer to place the point of suspension *exactly* at the *centre of gravity*; for the

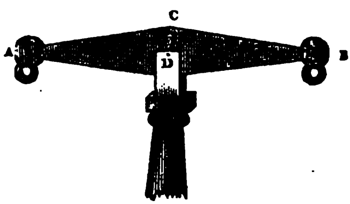

Fig. 128.

would then remain at rest in any attitude, and would vibrate when either end is depressed (310). Neither would it answer to place the support *beneath* the centre of gravity; for, in that case, the moment the slightest obliquity of the beam occurred, the beam would be overturned (313). The prop of a scale beam is therefore always placed a very little *above the centre of gravity.*

332. Steel-yards are less accurate than balances. Fig. 129 represents a steel-yard suspended by the hook C from a firm support. The arm F B is four times as long as the arm F A: therefore, unless the former is made much lighter than the latter, the centre of gravity of the whole bar must be nearer to B than is the point of suspension; and consequently, the longer end will descend. To prevent this, the arm F B is thinned off to very narrow dimensions towards B, in order to lessen its weight as much as possible, while F A is made thick and massive, to assist in balancing it. But all bodies are acted upon by gravity in the same manner as if all their matter was concentrated in the centre of gravity (310); now, let E be the centre of gravity of the long arm, and D that of the short arm: then the steel-yard cannot rest horizontally unless the weight of F B × F E is equal to the weight of F A × F D. As steel-yards are employed for measuring very heavy bodies it is necessary to make F A so short that no convenient thickness will enable it to counterbalance the long arm. The body which we intend to weigh by the steel-yard is generally suspended by a hook from the shorter arm; and in order to subject proportional weights at opposite ends of the bar to the law already laid down for bodies connected by rods supposed to weigh nothing (321), we must load the shorter arm sufficiently to bring the centre of gravity of the whole instrument to F, before we employ it in judging of the weight of other bodies. This is usually done by large dealers, but is often neglected by retailers and domestic operators, to the injury of others or themselves.

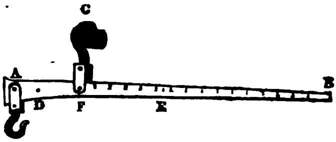

Fig. 129.

333. The mode of estimating weight by the steel-yard is easily explained. The upper edge of the long arm is divided into a scale of equal parts, continued from its free extremity as nearly as possible to the point of suspension. In Fig. 129,* this scale includes sixteen divisions, and the short arm is equal

to four of those divisions. Here, then, if the steel-yard be properly balanced, a weight of 4 ounces suspended at B would balance a pound suspended at A. If this weight be moved from one division to another, towards the point of suspension, it loses one-sixteenth of its distance from the centre of suspension, which is now the centre of gravity, at every step; and as the effect of gravity upon it is proportional to its weight multiplied by that distance (330), it must also lose one-sixteenth of its effect in balancing the body at A. But its first or greatest effect was capable of balancing a pound: it therefore balances one ounce less for every division of the scale through which it moves: each division is therefore the measure of one ounce of the weight of a body suspended at A. If a weight of 4 pounds were substituted for the 4 ounces, on the longer arm, each division would become the measure of a pound: and larger weights may be employed on the same principle to any extent.

334. Balances are sometimes made of angular or curvilinear beams. Let A C B, Fig. 130, be an angular beam suspended from the point C, with weights appended to the arms at A and B. It is evident that the centre of gravity is below the centre of suspension in this case; therefore it must be somewhere in the perpendicular line dropped from that point. But it cannot be found in the short part of that perpendicular line which is within the beam; for there is no point within the beam about which the two arms could balance each other in every attitude. Thus you perceive that the

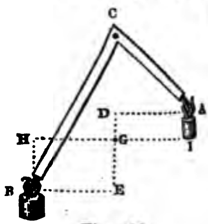

Fig. 130.

centre of gravity of a body is not necessarily within the body itself, but may be in the open, unoccupied space between its several parts. Therefore, from C let fall a perpendicular line in the direction of gravity, D E being a part of this line, and let G be the centre of gravity. Through G, draw the horizontal line H I, and, from the points of suspension of the two weights draw the lines A D and B E perpendicular to E D; also draw I A and B H parallel to D E. It is evident that the gravity of the weight at B has the same tendency to cause the arm C B to revolve upon the point C, that it would have if H I were an inflexible rod attached immoveably to that arm, and the same weight were attached at H: also; that the weight at A has the same tendency to turn the arm C A as it would have if that arm were connected with the rod H I, and the weight

led at I. But if H I were such a rod, and the
; attached, the centre of gravity G would be
upported by suspension from C. Now, when
gravity of two bodies is supported whether by
suspension, they will be in equilibrium when
f one multiplied by its distance from that centre
ie weight of the other multiplied by its distance
ne point (323). Therefore, if we neglect the
ie angular beam A C B, this balance will be in
when B × H G = A × I G. But H G is equal to
to A D; therefore the balance will be in equi-
1 the weight at A multiplied by A D—its per-
stance from D E or C E—is equal to the weight at
by B E—its perpendicular distance from the same
s this result has no dependence upon the degree
or the kind of curvature given to the beam, the
plies to all weighing beams and steel-yards with-
m.

ommon form of balance is seen at Fig. 131.
its a light rod, considerably enlarged, to form a
. It may be either straight or curved, and is
y a pivot at E, which allows it to play freely
e *quadrant* or
of a circle B G.
s affixed to the
olumn which sup-
pparatus; and a
c quadrant A D is
the rod in the
resented in the
ollows all its mo-
r this quadrant
r fine wire, secur-
l dependent from
ty D. It gives
mall ring or hook,
is suspended a
F. The larger

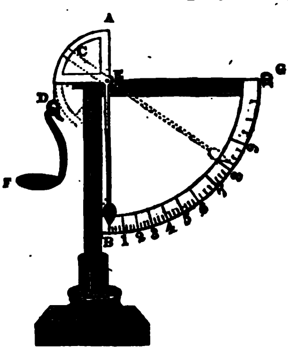

Fig. 131.

; is permanently attached to the pillar, and is
that each division represents a pound, or some
f weight. When unloaded, the rod hangs in
in the attitude represented in the figure; but
ng is placed in the scale, the extremity B rises
; the weight of the article upon the graduated
ascends, the lesser quadrant subsides and delivers

a portion of its cord or wire, which, still preserving the direction of a tangent to the arc, keeps the weight in the [illegible] always at the same distance from a line dropped perpendicularly from the point of suspension; the effect of this weight, therefore, remains the same in every attitude of the [illegible]. Not so the effect of the weight B: This is continually increasing as B recedes from the perpendicular line: and the scale is therefore graduated, not according to the length of the arcs described by the extremity B, but according to the *sines* of those arcs—*the sine of an arc being a line passing from one extremity of the arc perpendicularly to a radius drawn through its other extremity.*

336. It is now time to speak of the mode of finding the centre of gravity or equilibrium in complex systems containing more than two bodies. Let A, B, C, D, E, Fig. 132, represent four bodies of which we know the respective weights, forms and positions. We desire to know the common centre of gravity or equilibrium of all these bodies. Find, by the rule already laid down (327), the centre of gravity of A and B, represented by the large dot in the line between those bodies in the figure. Then, considering all the matter in A and B as concentrated in this centre (325), calculate the centre of gravity of these two bodies united and the body C. This is represented by the large dot in the line joining the first centre with the body C, and this second dot is therefore the centre of gravity of the three bodies A, B and C. Consider these three bodies as concentrated there, and proceed as before with the sum of their quantities of matter and that of the body D, to determine the centre of gravity of these four bodies, as represented by a third dot in the line joining the second centre with D. By the same operation repeated and including the last body E, you can determine the point F, which is the common centre of gravity or equilibrium for all the bodies in this system.

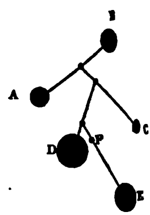

Fig. 132.

337. Every body in nature may be viewed as a system of independent atoms. But as we cannot number these atoms it is impossible to calculate the position of their centre of gravity in the manner just described, and some readier mode is necessary. In irregular bodies the determination of the centre of gravity by calculation is exceedingly difficult, and it is much easier to ascertain it by experiment (311). But in all regular solids of equal density throughout, the calculation

easy. We have space here only for a few results, leaving you to prove their truth for yourselves after having studied geometry.

338. The centre of gravity in spherical and spheroidal bodies of uniform density is the geometrical centre of the figure or space occupied by the body. That of circular or elliptical tables is in the middle of their thickness and at their geometrical centre. That of the cylinder and all prisms, is in the middle of the axis.

339. If three cylinders be so arranged that their axes form an equilateral triangle, the proper centres of gravity of the several sides are in the centres of their axes, and lines drawn perpendicularly from these points will meet at the centre of gravity of the system. The same thing is true of any number of cylinders ranged in the form of sides to any regular polygon; and, as a polygonal table may be regarded as made up of a number of similar and concentric systems of cylinders, the centre of gravity of all regular tabular polygonal bodies may be found in the middle of their thickness and at the point where lines drawn perpendicularly from the middle of any two of the sides intersect each other. If a line be drawn from either angle of a triangular table to the middle of the opposite side, the centre of gravity will be found in the middle of the thickness of the table, at the distance equal to two-thirds of the length of this line measured from the angle, or one-third measured from the side.

340. If bodies of equal weight be ranged in such a manner as to correspond with the angles or the middles of the sides of any regular polygon,—that is; if they be arranged at equal distances around a common centre,—their centre of gravity may be found by the rule just laid down for the polygonal system of cylinders (339): for it is of no consequence whether the weight of each side be diffused evenly throughout the extent of that side, concentrated in one mass into its centre of gravity, or gathered into two equal masses at its opposite extremities, which are equidistant from that centre.—The effect in all these cases is the same. For the same reason, if three bodies of equal weight correspond with either the angles or the middles of the sides of any triangle, their common centre of gravity may be calculated by the rule just laid down for triangles in general.

341. The centre of gravity of any parallelopipedon is found in the middle of a line drawn from the intersection of the two diagonals of either of the faces to the intersection of

the corresponding lines on the opposite face. That of a cone is found in the axis of the figure, at the distance of one-fourth of its length above the middle of its base: That of a hemisphere, is perpendicularly over the middle of the base, at three-eighths of the height of the dome. The calculation of the position of this point in all the regular polyhedrons is not materially more difficult, but in an elementary work it is unnecessary to enlarge upon this subject.

342. You will read, in many works on natural philosophy, of the centre of gravity of lines, surfaces and spaces, but all such applications of the term are absurd; for that which has no material existence can not gravitate, and can have no centre of gravity.

343. *Of Centres of Spontaneous Revolution.*—You are now fully acquainted with the fact that the force of gravity in all bodies and parts of bodies is proportional to the quantity of matter which they contain, because gravity is a property of all matter. But *inertia* is also a property of all matter; hence, whether in motion or at rest, the inertia of all bodies and parts of bodies is proportional to the quantity of matter which they contain. Now, inertia may be regarded as a force; for by its means all bodies *resist* any change of their existing condition of motion or rest; and as it is distributed throughout all matter in the same manner with gravity, the centre of gravity must also be *the centre of inertia* or of mechanical *resistance;* and either of these three names may be applied to it with equal propriety. Therefore, if the system of two bodies A and B, Fig. 133, were in motion in such a manner as to preserve a direction constantly parallel to their position in the figure, and were then suddenly arrested by any force applied at G, (the centre of gravity) the whole system would be brought suddenly to rest; because the bodies move only in virtue of their inertia, and G being the centre of inertia, the inertia of A and B would exactly equipoise each other at this point; and the momentum of the system would act as if all the matter therein were concentrated about G.

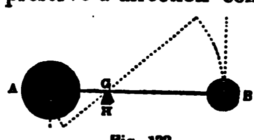

Fig. 133.

344. If the force opposing the motion in this case were more than sufficient to check the advance of the system, the bodies A and B would be thrown back with proportional velocity in the direction of the superior force, according to

laws of impact developed in the last section; but all of the system would remain unchanged in their relative position, because the equipoise of the inertia of the two bodies would not be disturbed by the opposing force. On the contrary; if the opposing force were too feeble to check the motion of the system, it would merely destroy a portion thereof, without affecting the equipoise of the remainder; the system would then continue to advance with diminished velocity, according to the laws of impact.

345. If the opposing force were applied on either side of the centre of inertia G, there would no longer be an equipoise on opposite sides of the point of action; but, the inertia of one of the bodies preponderating, it would be less retarded than the other body. Let us suppose this force to be applied between G and B. In this case, the motion of A and that of the centre of inertia G would be less retarded than that of B. But these two bodies are preserved within a given distance of each other by the rod connecting them. Therefore, as one body moves faster than the other, they must change their relative positions in consequence of the application of such a force.

346. Now; under the circumstances mentioned in the last paragraph, the whole system must feel the effects of the force applied, which changes its existing state of motion, and must resist this change by its inertia: but this resistance being offered equally by each particle in the entire system, the combined effect of all these resistances must equipoise each other at the centre of inertia or *resistance* G: or, in other words; the effect of mechanical action or reaction upon the whole system will be exactly the same as if all the matter in the system were concentrated in the centre of gravity or inertia, and the same force were then applied in the same direction at that point. The centre of gravity of the system will therefore be brought to rest, or it will be thrown back in a direction parallel to that of the force applied, or it will continue to advance with diminished rapidity, according to the violence of this force, precisely as if it were placed under the circumstances described in paragraph 344.

347. Not so, however, *the different parts of the system:* for these are compelled to change their relative position by the force (345); and as they are preserved at a fixed distance from the centre G by their connecting rod, or by the bond uniting the parts of the system, whatever that may be, they can only do so by revolving around G as a centre.

348. These facts being almost too profound for beginners, though capable of very clear mathematical proof, we trust that the foregoing remarks will enable the pupil to comprehend the following laws of mechanical force; remembering that forces produce their impression in the perpendicular direction only.

(*a*.) Bodies act and are acted upon by all forces in the same manner that they would be if all their matter could be concentrated at their centres of gravity, while their figures remained impenetrable.

(*b*.) When force is applied to any body or system of bodies in a direction not passing through the centre of gravity or inertia, the body or system viewed as a whole, is affected in precisely the same manner as if the force had acted in a direction passing through that centre, which will therefore be put in motion, arrested, accelerated, retarded or brought to rest, according to the rules of direct impact. We will explain this law by a figure. Let A M B N, Fig. 134, represent any body at rest in space, of which A B is an axis and C the centre of gravity; and let this body be impressed by a force acting at F in the direction E F. Now if this force be sufficient, when applied in the direction M C, to drive the centre of gravity by an absolute motion from C to D in one second of time, it will cause that centre to move through the same line C D, even when it is applied at F; and the line C D will also be parallel to E F.

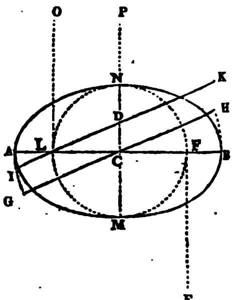

Fig. 134.

(*c*.) When force is applied to a body or system of bodies in a direction not passing through the centre of gravity or inertia, this force causes the body or system to revolve relatively around the centre of gravity or inertia with as great velocity as if this centre were absolutely fixed in space. For the centre of gravity is also the centre of *resistance* (343); and the *resistance* of the whole mass being equally balanced about C, the force acting in the direction E F causes the whole body to revolve round C exactly as if A C B were a weighing beam suspended by inertia instead of a cord or prop at C.

349. But, if the centre C were permanently fixed, it is

vident that the force applied could not cause the extremity B to advance without compelling the extremity A to move backwards to a proportional extent. Therefore when the centre C is advancing along the line C D, all parts of the body between C and B continue to advance relatively to the centre, and all parts between C and A continue to recede *relatively*, so as to revolve in relative circles around C. Now suppose that the force applied in the direction E F is such as would cause the extremity B to revolve as far as H, and the extremity A to retreat as far as G, if the centre were fixed, in exactly the time required to carry the centre of gravity to D, when it is moveable. On the former supposition, at the end of this time, the axis A B would be found in the line G H; but while it is endeavouring to assume this position, the centre and the whole body, together with the whole axis are carried forward in a direction parallel to E F and equal to C D. The extremity B will therefore be found at K instead of H. Therefore the line I K will represent the position of the axis at the end of one second of time, and L will represent the point of intersection between the new and original directions of the axis. Here it will be perceived that while B has advanced to H, A has actually retreated to I. At any fixed instant of time then, all the matter between L and B is absolutely advancing in space, and all between L and A is retreating in space.

350. But the matter about the point L is really moving around the relative centre, C or D, in a relative circle. If the *line* A B be supposed to advance with the centre, in a direction constantly parallel to its first position, all the *matter* about the circle L M F N must come successively into the same relative position with regard to A and B;—that is; the distance A L and B L will remain constantly the same; and at all times, the matter, if there be any, between L and B will be advancing, while that between L and A is receding. Therefore, L is a relative point which advances along the line L O with the same velocity that the centre of gravity advances along the line C P. Such a point is called *a centre of spontaneous revolution*, because the portions of matter on opposite sides of it, if there be any, are absolutely revolving about it in opposite directions.

351. If the angular velocity communicated to B had been less, the force applied remaining the same—which would have been the case had E F been nearer to C the centre of inertia,—the point L would have been proportionally farther from C; and hence, it might be placed entirely beyond

the body, somewhere in the line B A produced, which would then constitute a virtual or theoretical centre of revolution. In this case no part of the body could ever display a retrograde motion in space, but all parts would advance with a velocity alternately accelerated or retarded. It has been calculated that if the earth received its diurnal revolving motion from the projectile force which urged it forward at the beginning of its career around the sun, that force must have been applied at the distance of about twenty-five miles from its centre.

352. It is obvious, then, that there must be somewhere within or without the matter composing any body or system of bodies put in rotary motion by a projecting force, a virtual or real centre of spontaneous revolution. Let A B, Fig. 135,

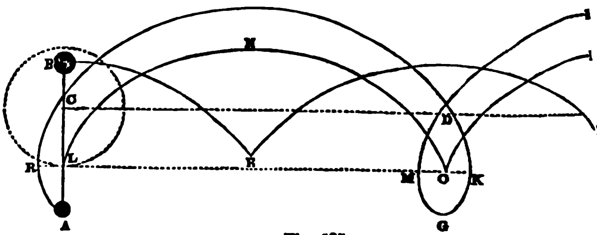

Fig. 135.

be a system of bodies, C the centre of gravity and L the centre of spontaneous revolution. Conceive the force to be applied somewhere between C and B in such a manner as to cause C to describe the line C D while the system makes one revolution around this point. With the radius C L describe the circle represented by dots in the figure. Here, the moment that rotation commences, the relative point L will advance along the line L K with a velocity and direction equal and parallel to that of the centre of inertia C; and all the matter which is above the line L K will be advancing in space, while all the matter which may be brought below that line from time to time will recede in space until its revolution around C as a relative centre causes it to rise once more above the line (348, *c*.). The system therefore moves like a rolling wheel (270) of which the radius is the distance between the centre of gravity and the centre of rotation, the road being represented by the line R K, the body B placed on one of the spokes of the wheel, and the body A upon the opposite spoke produced. It is evident that, while the dotted circle rolls along the line L K, carrying with it

the point L, which constantly represents the bottom of the wheel, *the matter* about this point must revolve with the circumference, and must therefore describe a succession of cycloids L, N, O, I, &c., while the body B describes a succession of curves, forming a series of modified cycloids B, E, F, &c., and the body A describes a series of looped curves—also modified cycloids—A R K G M H, &c. B then, will be continually advancing in space, because it never passes below the line L K; but A will move forward when above the line, as from R to K and from M to H, and will recede when below the line, as from A to R, and from K to M.

353. Instances of centres of spontaneous revolution, are frequently witnessed in the common transactions of life. When the Indian casts his tomahawk, or the Spaniard his knife at an enemy, the missile is not thrown with its edge or its point directed at all times towards the object of attack, but receives a rotary motion around its centre of gravity which renders it still more formidable in giving a wound. When a billet of wood lying athwart a block or a log is incautiously struck by a wood-chopper upon its projecting extremity, it may be whirled into the air with great force, and will then form for itself an axis of spontaneous revolution; so that while the centre of gravity steadily pursues the parabolic course of a projectile (239), the extremities of the billet may advance or retreat alternately during their revolution, like the body A in Fig. 135; and instances have been known of men being killed by a blow received in rear from a heavy stick moving in this manner after the centre of gravity had passed entirely beyond the person. Fig. 136 represents a light bar of wood A B supported upon the edges of

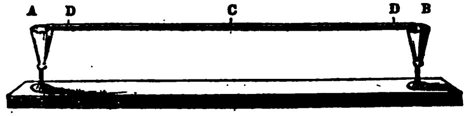

Fig. 136.

two wine-glasses. If this bar be struck with moderate force upon its middle point C, the glasses will be crushed; but if a walking cane or a poker be brought down upon this point with great velocity, the cohesion of the bar may be overcome before time is allowed for the communication of momentum to the whole bar. In this case, the bar being instantly broken, the pieces immediately begin to revolve around their respective centres of gravity, which at the same time descend towards the table according to the law already

explained (348, *b*), and by this combined action, each piece may form for itself a centre of spontaneous revolution, at some point D: so that the extremities resting on the glasses may be made to rise up instead of being driven downward at the moment of the blow, and the fragments of the wood then fall harmlessly upon the table, leaving the glasses uninjured.

354. The Earth and Moon revolve around their proper centre of gravity, while, at the same time, that centre itself revolves around the common centre of gravity of these two bodies and the sun, towards which they gravitate. The same thing is true with regard to the sun and each of the other planets, with its satellites, if it have any: Therefore all the bodies composing the solar system are constantly describing as many series of modified cycloids, complicated and disturbed in a thousand ways by their mutual attractions, but capable of accurate calculation and dependent upon the same laws of gravitation and inertia that regulate the motion of the wood-chopper's billet, or the system represented in Fig. 135. The heavens are crowded with monster suns and planets of vast size, in comparison with which those of our own small constellation appear almost contemptible; yet all pursue their course in their gigantic orbits, bound by the same bonds and impelled by the same forces: thus you perceive how the humblest accidents of common life may illustrate the grandest works of the creation, and you will be less surprised to hear that the fall of an apple induced the train of thought that led to the discovery of the harmony of the spheres, and almost warranted the bold expression of the poet:

> "Nature and nature's laws lay hid in night;
> God said; 'Let Newton be!'—and there was Light."

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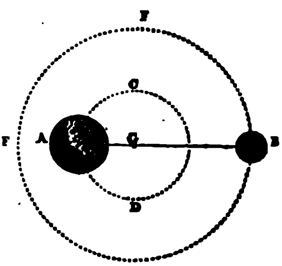

Fig. 137.

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356. As this law of equilibrium in all bodies revolving in a system is independent of the nature of the bond which unites the several bodies at their proper respective distances, any body or combination of bodies, when made to revolve in any manner, will revolve relatively around the centre of gravity the moment it is left free to do so. Thus; suspend a heavy

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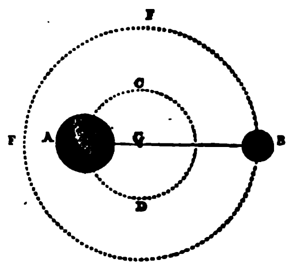

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bar by means of a tightly twisted cord attached around its centre of gravity. Then suffer this apparatus to revolve by becoming untwisted. In this case the cord remains undisturbed, because the circular motion of the bar leaves the centre of gravity at rest. By the application of force to the bar, while turning, we may impel the centre of gravity in any direction at pleasure, causing it to describe circles or ellipses of various sizes or to vibrate like a pendulum; but the relative motion of the bar around this centre will remain unchecked by all these efforts.

357. If you suspend the bar from a point considerably removed from the centre of gravity, C, Fig. 138, so that the extremity A may preponderate, and then repeat the former experiment, the rod will not revolve around the point of suspension D, though the force which causes the revolution is applied by the twisting cord at that point. On the contrary, D will revolve in the circle D E, while each of the extremities of the bar will describe its appropriate circle, and the centre of gravity C will remain as nearly at rest as the oblique action of the cord will allow it to do. The action of the earth's gravity and the resistance of the cord compels the bar to preserve an oblique position, so that the several circles are found in different planes; but if you make due allowance for this circumstance, and employ a cord so long that its direction shall never be rendered very oblique by the forces applied to the bar, you can test in many ways the truth of what has been said of the motions of the heavenly bodies by this simple little contrivance.

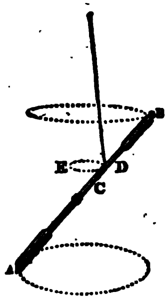

Fig. 138.

358. When any part of a machine is intended to move by rotation, the axis or pivot should pass, if possible, through the centre of gravity. If a grindstone, for instance, be thus balanced upon its axis, the centrifugal force when it is put in motion is exerted equally in all directions, and the friction on the axis is reduced as much as possible: but if the axis be placed in any other situation, the heavier portion of the stone having most momentum, tends constantly to fly off, and thus equally increases the friction and wearing of the opposite side of the axle.

359. *Of the Centre of Percussion.*—Before entering upon the subject of the mechanical powers we must notice another

centre of action resulting from the manner in which bodies in motion impinge upon others relatively at rest. It is called the *centre of percussion.* If a long bar, or a heavy cane be raised in the hand and then made to descend upon any fixed object, the different parts of the weapon move with different degrees of velocity, and consequently momentum. If the farther extremity of the bar strike the object at which it is aimed, a considerable portion of the momentum of the weapon is suddenly checked; but that portion of the matter in motion which is between the hand and the point of collision still struggles to move onward, and can only be arrested by the resistance of the hand. If the bar be heavy and the blow vigorous, the weapon may be thus forced from the grasp. But if the end of the bar projects far beyond the object struck, so that the point of collision is near the hand, the downward tendency of the nearer portion is reversed while the more distant extremity endeavours to continue its course, causing the end held in the hand to fly up unless forcibly prevented; and if the weight of the bar be considerable, the consequent blow may be attended with serious consequences. Between these extremes there is a point at which the momenta of the opposite extremities balance each other, so that if the blow be received at this point, all the momentum of the weapon is suddenly destroyed, and the hand experiences no impression from any part of it. This point is the centre of percussion.

360. If the farther extremity of a weapon of this character be made much heavier than that held in the hand, it is evident that its momentum must be proportionally increased, and consequently the centre of percussion, where the opposite momenta balance each other, must be drawn much nearer that extremity. If the weapon be constructed with a light handle carrying a heavy weight, the centre will be found within the substance of the weight itself, and it may be used with perfect safety in pounding or striking; for then, the whole momentum will be checked at every blow, and the hand will not be hurt. It is for this reason that hammers, axes, mauls, and all instruments for similar purposes, are provided with heavy heads and long, light handles. If a body be moving in a direction constantly parallel to itself, the centre of percussion agrees with the centre of gravity; but if it be vibrating like a pendulum, it agrees with the centre of oscillation.

361. In machinery, it is often necessary to make one mass of matter impinge upon another with much force; and if the

weight of the impinging body be not so regulated as to make the centre of percussion agree with the point of collision, there will be great waste of power, with severe jarring and a rapid wearing of the parts of the machine.

OF THE MECHANICAL POWERS AND SIMPLE MACHINES.

362. The intention of man in the construction of machinery is either the production or the arrest of motion in material substances; and the means by which he accomplishes this purpose is by opposing against the pressure, resistance, or impetus of the object on which he operates, some equal or superior force acting in an opposite direction. In estimating the effect of such contrivances there are always two things of paramount importance to be considered—1st. The force to be overcome, which may be properly termed *the resistance;* and 2d. The force designed to overcome it, which being the means by which our object is obtained, may be termed *the power.*

363. In almost all machines the direction in which the force is applied is changed by the intervention of the machine: thus; when it is desirable that a heavy body should be elevated on the outside of an edifice from the ground to the level of one of the upper floors of the building, while convenience requires that the force should be applied by individuals standing on the pavement below, we may employ a simple rope thrown over a little wheel called *a pulley,* A, Fig. 139, revolving upon a pivot at C, and permanently secured to a beam B, placed above the point to which the body is to be elevated. One extremity of this rope is attached to the body, the weight of which *constitutes* the resistance to be overcome, and the power, which in this case consists of human force, is applied to the opposite extremity. In this contrivance it is evident that the pulley has no other effect than to change the direction of the power applied by the workmen at one extremity of the rope so as to act in direct opposition to the resistance offered by the body at the other extremity.

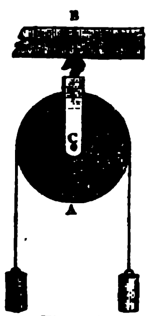

Fig. 139.

364. Many machines or portions of machines are contrived solely for the purpose of changing the direction of forces in order that they may be applied more conveniently. Of this class is the common scale-beam, which reverses the action of the weights placed in opposite scales, and enables each to

upon its antagonist in the upward direction, although its tendency is downward. We shall presently see that it sometimes convenient even to employ machines that act mechanical disadvantage, merely to gain a convenient change in the direction of forces. But by far the greater number of such inventions are intended to enable a small amount of power to overcome a greater amount of resistance, in other words, to obtain a mechanical advantage (322). This purpose always requires the aid of a bar, a wheel, a reverted rope, or some other contrivance of which various portions are moving in opposite directions at the same moment, like the two arms of a balance, two opposite spokes of a coach-wheel, or the two ends of the rope in Fig. 139; but no such change can be effected unless that part of the apparatus by which it is accomplished is supported or fixed at some point round which it may turn or revolve: thus the balance requires the prop, called a *fulcrum;* the coach-wheel, its *axle;* and the reverted rope or pulley, its *pivot;* which are called *centres of action.*

365. You must not permit the term *mechanical advantage* to deceive you into the idea that it is possible by means of any machine to multiply momentum or moving force. This is utterly impossible; because momentum can neither be communicated nor destroyed except by some other momentum equal in degree. From this fact we derive a general law by which to determine the power or mechanical advantage gained by means of any machine whatever, however complicated its structure, if we neglect the effect of friction. It is as follows:—*In every machine, the momentum of the power is exactly equal to the momentum of the resistance.*

366. This law has been sufficiently illustrated already in the section on equilibrium: Thus, the balances represented in Figs. 129 and 130, preserve their equilibrium, because the momenta of A and B—the power and the resistance—are equal to each other, whether the levers be in motion or at rest: for, when at rest, their momenta are equal to nothing, and when in motion, they move with velocities inversely proportioned to their weight (326).

367. The apparently various nature of the resistances to be overcome by machinery makes it difficult or impossible to apply this law in certain cases, though its truth is universal. Philosophy has not yet determined all questions relating to the nature of friction and cohesion; so that we cannot calculate the exact amount and nature of the momentum communicated to a fluid when it is partially set in motion by

any force, or that of the momenta communicated to the molecules of matter when it is broken or crushed by the destruction of its cohesion. Therefore, if a machine be designed to act upon resistances of a character different from those produced by gravity, it is often necessary, when we wish to arrive at certainty, to test its power by experiment, although the law just laid down assists us greatly in explaining and applying the results of such experiments.

368. It is sometimes convenient to refer to another law which is a direct consequence of that laid down in paragraph 365, even if it be not considered as the same law differently expressed. By reference to either of the balances figured in the section on equilibrium, you will perceive at once that if a power of ten pounds applied at one extremity, is made by means of such a machine to raise a weight or overcome a resistance of twice ten pounds at the other extremity, the power must move through two feet while the resistance is moved through one foot. If the power be only one-third as great as the resistance, it must be removed so far from the fulcrum or centre of action that it will pass through three times the distance described by the resistance in the same space of time, &c. Now, as precisely this difference of velocity is necessary to make the momenta of the resistance and the weight equal to each other, and as this equality is the object accomplished in all mechanical contrivances (362), it follows that, in any machine, whatever may be its construction, when the power moves through twice or three times the distance described by the resistance, the quantity of power required to move the machine will be only one-half or one-third as great as the resistance; or, in other words, the mechanical advantage gained by the machine will be a doubling or tripling of the advantage. Hence: if, in any machine, you divide the velocity of the power by the velocity of the resisting body, the dividend will represent the mechanical advantage or efficiency of the machine. Therefore: *In all mechanical contrivances, what is gained in power is lost in time, and what is gained in time is lost in power.*

369. Thus; if a machine acted upon by a given power—say the force of one man—will lift a given weight—say ten pounds—through a given distance—say one foot—in a given time—say one second—it will require twice the power or the force of two men to raise the same weight through twice the distance in the same time—or to raise twice the weight through the same distance in the same time—or to raise the weight through the same distance in half the time. The body of a

man is a machine, and so is that of a horse. If the body of man weighed nothing, it would require the same amount of labour to carry a barrel of apples into the garret by taking the apples up one at a time, as to carry the whole barrel at once, though lazy people who regard time as of little value and over estimate labour, are much given to practices resembling the former mode of doing business: They forget, however, that by the former method, the weight of the porter as well as that of an apple has to be raised to the whole distance against gravity at every trip: thus the exertion is multiplied many times, by the very process so often adopted by the lovers of ease. The laws of Providence were not instituted to favour the idle.

370. Let us now apply the principles just laid down to the explanation of those simple machines which are commonly called *The Mechanical Powers.* Every compound machine, however complex in appearance, may be analyzed and resolved into a combination of two simple machines called *the lever* and the inclined plane, each of which, however, may be constructed on different models or plans without any essential difference of action.

371. The common lever is simply an inflexible or tough bar, designed for raising weights or otherwise overcoming resistance by being placed across a fulcrum, which is made its centre of action, while the weight to be raised or the resistance to be overcome is applied at one part of the bar, and the power acts at another. The common scales and the common steel-yard are common levers, in which the resistance is the gravity of the body to be weighed, and the power is the gravity of the mass or masses of matter, commonly called *weights*, which are suspended from the opposite arm of the balance. Figs. 140 and 141 represent common levers.

Fig. 140.

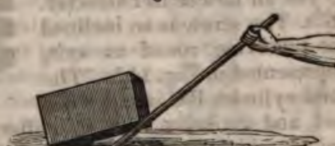

Fig. 141.

372. A class of levers equally simple, though apparently more complex, consists of such machines as are provided with a wheel having a barrel or axle passing

through its centre, with pivots at each extremity, ' which it is supported. The power is usually applie the circumference of the wheel and the resistance at circumference of the axle; though the opposite arr ment is often seen. A handle which acts like the r of a wheel is sometimes substituted for the wheel i Many names have been given to this class of contriv but it is generally known by the title of *The wheel and* It includes the *windlass*, the *shaft and pitman*, the ca *and handspike*, &c.

373. The *pulley*, which has been already in part des (363), constitutes a third class of levers. Pulleys are fixed or moveable: the former are employed simply to the direction of force when applied by means of c chains, but the latter are designed to give a mechani vantage, by causing the power to move through a space in a given time than the resistance. Famili ples of the fixed pulley are seen in the little whe which the window cords pass in their route f frame to the weights which balance it. Exampl moveable pulley will be given hereafter. The w metallic frame in which one or more pulleys quently enclosed is termed *a block*. By means of blocks and pulleys the machinery of a ship or other vessel is chiefly regulated.

B

D

C Fig. 142.

374. The nature and some of the laws of the common inclined plane have been explained in a previous chapter (255), and no farther examples are necessary to give you an idea of its character.

375. The screw is an inclined plane revolving round an axis, as represented in Fig. 142. The central cylinder B C is called the barrel, and the helix, or as it is often erroneously c spiral D, which is seen encircling the barrel, is te thread of the screw. When the screw is applie chinery, it is usually adapted to another and si clined plane, cut into the circumference of a hollow B, Fig. 143, which fills up all the interval of the the screw proper A C. The term screw, howev plied equally to the screw proper B, and to the

ne in the cavity which causes it to vance when turned. One of these parts the machine is very seldom employed act without the other, except in com-ned machines involving several different echanical powers. A screw, therefore, its common form, consists of two in-lined planes reacting upon each other, one f which being fixed, will not suffer the ther to move without either advancing r retreating.

Fig. 143.

376. When convex metallic screws are employed to act upon wood, as in attaching planks together, they usually form the concave inclined plane or *thread* for themselves by compression as they advance. This compression increases friction very greatly; but friction in this and many other cases is an advantage, because it prevents the pieces confined together from being easily separated by forces which tend to make the screw revolve and unwind itself. The wheels of carriages are prevented from running off from the axle by means of screws. Each extremity of an axle is provided with a convex screw, and upon this is fixed what is called "a nut." This is a very short concave screw, filling up the interval of a few turns or revolutions of the convex screw, and producing upon its thread sufficient friction to prevent the lateral pressure of the hub of the wheel from winding it off from its position. Nuts of this character are generally used whenever two pieces of machinery are required to be bound together securely without preventing them from moving freely upon each other. The screw is very rarely employed as a means of applying force except when aided by the common lever, as at A, Fig. 140, or by some other mechanical power.

377. The common wedge is a double inclined plane composed of two similar planes united by their bases, as represented in Fig. 144, where D C corresponds with the bases of the planes, and the lines A C and B C represent the declivities or inclined sides of the planes. Of course, then, the action of the wedge as a mechanical power is governed by all the laws that apply to the simple inclined plane, which latter is not uncommonly employed as a wedge by

Fig. 144.

gunners in raising and directing cannon, &c.; but by far the most common application of this machine is in splitting timber, and the manner of employing it for this purpose is seen at E in the figure.

378. Like the screw, this contrivance produces very great friction, and on this account it can rarely be employed to advantage where the power applied is simple pressure or any other constant force. Nor can the lever be often usefully employed in driving the wedge. The wedge is usually driven by *percussion* or sudden blows effected by means of hammers, mallets or mauls; and the effects thus produced cannot be compared with the effect of simple weight or simple pressure, such as produces the equilibrium of rest upon levers and pulleys. The pressure of a ton might be required to drive a nail—a kind of wedge—into a board which it would quickly penetrate under moderate blows from a hammer weighing only a few ounces.*

379. Though there are in reality but two mechanical powers, the various modifications of machinery for the employment of these powers are so different in appearance and ordinary application that they are usually described as distinct classes of machines, and there is some convenience in following this custom. Let us then proceed to apply the principles with which you have been made acquainted to the explanation of the actions of the "six mechanical powers"—The Lever, the Pulley, the Wheel and Axle, the Inclined Plane, the Screw, and the Wedge: but in so doing we leave out of view, as heretofore, the effects of friction and the weight of the machines, unless where these forces are made a matter of separate comment.

380. *Of the Lever.*—The nature of the lever and the laws which are applicable to the calculation of its efficiency have been already explained. It will be remembered that the only essential difference between the lever and the balance

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* Pressure can only be measured by pressure, and momentum by momentum, just as a line can only be measured by lines, and a surface by surfaces: but the relation in point of quantity or effect between one degree of pressure and another, may be compared with the similar relation between the quantity or effect of one degree of momentum and another; just as one line is to another line of twice its length, as one surface is to another surface of twice its extent. It would be as absurd, then, to ask how much momentum would balance ten pounds of matter, as to ask how many lines will make up a given surface. Things which are essentially different in their nature cannot be compared, though their relative quantities may be.

does not lie in any peculiarity of the machine itself, but in the nature of the resistances which it is often required to overcome, and the character of the power employed in moving it. The laws of the balance, whether straight or bent, are equally applicable to this mechanical power. You will remember that the effect of any given weight,—and therefore any given amount of momentum—in turning or endeavouring to turn a straight balance or lever around the centre of action or fulcrum is always proportional to the distance between the centre of action and the point at which the force is made to act (326); and therefore, that the effects of different weights or momenta may be expressed by multiplying each by its respective distance from the centre of action;

381. This rule is not confined to balances or ordinary levers; for, if a long curtain or hat pin be secured to a wall and a weight be suspended from it at the distance of one inch from the wall, the tendency to break or loosen the pin will be just half as great as if the same weight were suspended at the distance of two inches from the wall; because the true centre of action in this case is at the surface of the wall where the pin enters it. By this simple rule, you will be able to determine the efficiency of any straight lever or combination of levers when the resistance and the power act in directions that are parallel to each other.

382. Levers are divided into three different orders according to the arrangement of the power, the fulcrum, and the resistance.

383. In the lever of the first order, as represented in Fig. 145, the fulcrum F is placed between the resistance R and the power P. If, then, the direction of the power applied by the hand at P and that of the resistance offered by the weight suspended from R be parallel to each other, this lever resembles in all respects the common steel-yard, and R multiplied by F R is equal to P multiplied by F P. Now, if F R be only one-fourth as long as F P, R will be four times as great as P. Hence; if you divide the long arm by the short arm of such a lever, you obtain the number of pounds of weight, or units of any other force which must be suspended upon the latter, in order to support one pound or one unit suspended upon the former; and if you divide the long arm into the short arm you discover what

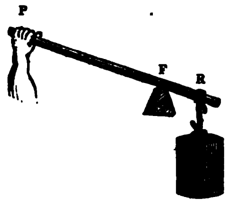

Fig. 145.

part of a pound weight or unit of force acting on the long arm will balance one pound or one unit on the short arm: that is, P : R : : F R : F P (235).

384. In the lever of the second order, as represented in Fig. 146, the fulcrum F is placed at or near one extremity of the lever, and the resistance R acts between the fulcrum and the power P. Here, then, the power and the weight are both supported by the same arm of the lever, and oppose each other by being made to act in parallel but opposite directions. But, in this, as in the former case, the effect of the resistance in endeavouring to turn the lever round the fulcrum will still be proportional to its force and its distance from the centre of action, and so will that of the power. Hence $R \times F R$ will still be equal to $P \times F P$, and P : R : : F R : F P; just as it is in levers of the first order.

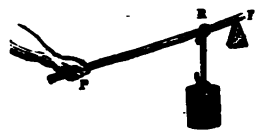

Fig. 146.

385. Levers of the third order, as represented in Fig. 147, resemble in all respects those of the second order, but the power and the resistance have changed places: that is; the power acts between the resistance and the fulcrum. In this case, it is evident that when the machine is in motion, the velocity of the resistance must be greater than the velocity of the power by so much as it is more distant from the fulcrum: and as the momentum of the power is always equal to that of the resistance (365), it is necessary that the amount of the power should be made proportionally greater than that of the resistance: Thus; if F P be only one-third of the length of F R, it will require a power equal to the weight of three pounds at P to support one pound at R, and thus the machine acts at a mechanical disadvantage. But still, the same relations exist in this as in the former orders; for $P \times F P$ is equal to $R \times F R$, and P : R : : F R : F P.

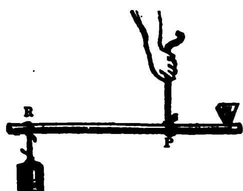

Fig. 147.

386. It is interesting, on many accounts, to consider the effect of levers of the different orders in producing pressure upon their fulcrum. In those of the first order, the fulcrum evidently supports both the power and the resistance, and no more: *the pressure upon it is therefore equal to the sum of the power and the resistance.* In those of the second order it is

equally obvious that all the resistance that is not supported by the power is supported by the fulcrum; and therefore, if we subtract the amount of the power from that of the resistance, the remainder will be the pressure on the fulcrum. As in levers of the third order the power and resistance change places, the latter must be subtracted from the former to obtain the pressure on the fulcrum; for it is evident that the power in this case sustains both the pressure and the resistance. Therefore, in both these orders of lever, *the pressure on the fulcrum is equal to the difference between the power and the resistance.*

387. If, in Fig. 145, we regard the little rope by means of which the weight is attached, as the fulcrum, and the pressure at F as the resistance, the lever will be converted from one of the first order into one of the second order. So, also, if a fulcrum be placed over R, Fig. 146, and F be a body which we wish to crush, the latter will be converted into the resistance to be overcome and the lever passes from the second into the first order. In neither of these cases are the relations between the power, the resistance and the fulcral pressure in any degree changed by the changes of their names and purpose. The differences between the several orders of levers are therefore rather apparent than real, and the same laws and modes of calculation are equally applicable to all of them.

388. In machinery, we often see a number of levers employed to act upon each other in such a manner as very greatly to multiply the power. Fig. 148 represents a system of this kind. The power is applied in the form of a weight at A; acting upon the lever of the first order A B, which has its fulcrum at F′. This lever acts upon a second D C, which reverts the direction of the force applied at A,

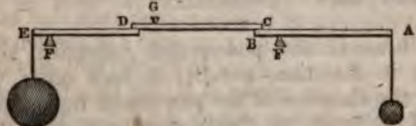

Fig. 148.

and therefore requires a fulcrum on its upper side at G. D C acts upon a third lever D E, which again reverts the direction of the force, and has its fulcrum at F. In this system the *resistance* of the first lever becomes the *power* acting on the second, and so on throughout the series. The relation

of the power to the resistance upon either of the levers is easily calculated upon the principles already laid down, but the most expeditious method of calculating the mechanical effect of the entire series is this:

Multiply together the several fulcral distances at which the power acts on the different levers, and divide the result by the product of all the fulcral distances at which the resistance acts; then divide the former product by the latter, and the quotient will represent the proportion between the resistance and the power. Thus; let E F, Fig. 148, be 1 inch in length; D G 1.5 inches; and B F 1 inch; these being the arms of the several levers on which the resistance is supposed to act; and let F D, G C and F′ A be each 5 inches in length; these being the arms on which the power is supposed to act. Then $5 \times 5 \times 5 = 125$ represents the effect of the power on all the levers collectively, and $1 \times 1.5 \times 1 = 1.5$ represents the similar effect of the resistance upon all the levers. Therefore $\frac{125}{1.5} = 83\frac{1}{3}$ will express the relation between the power applied at A, and the resistance that it will compensate at E: and one pound at A will balance $83\frac{1}{3}$ pounds at E. This rule applies to all all straight levers when the power and resistance both act at right angles with the levers, whatever may be their order.

389. Hitherto we have treated chiefly of straight levers; but many of those most constantly employed, such as the claw-hammer and the crow-bar, are angular or bent. In these, also, if the power and resistance act at right angles with the corresponding arms of a lever, the rule given in paragraph 388 is strictly applicable, though not always convenient. Levers of this character are often used in raising weights, after the manner of balances, and the mode of their action under such circumstances is seen in Fig. 130, page 148.

390. Whenever the power and resistance act upon a bent lever in directions parallel to each other, instead of measuring the distances of the power and resistance from the fulcrum of the lever, we should measure their distances from a line drawn through the fulcrum and parallel to the direction in which the forces act: Thus; if A C B, Fig. 149 be a curved lever, such as is often used in ringing a dining or drawing-room bell, B L will represent the direction of the resistance and A K that of the power applied by the hand. In this case, it would not do to multiply the power and the resistance by the lengths of their respective arms of the lever;

or these might be made of various lengths by changing their curvature without altering in any degree the efficiency of the machine. Through the fulcrum C draw the line D E parallel to the direction of the power and resistance. From A draw A G perpendicular to D E, and from B draw B F also perpendicular to D E. Then, on this lever, the power : the resistance :: F B : A G. To prove this, we have only to draw the line H I perpendicular to D E

Fig. 149.

and passing through the centre of action C. By so doing we complete the parallelograms H E and F I. H C will then be equal and parallel to A G and I C to B F. Now, if H I were a straight lever of the first order, it is evident that the power would have exactly the same effect in turning H I around the point C, as it has to turn A C B around the same point; for, if the supposed arm H C and the real arm A C were firmly joined together as one piece of metal, there could not be any difference between the effect produced by pulling this arm towards K by means of a wire attached to the corner H, and that produced by pushing it towards the same point with the same degree of force applied directly by the pressure of the hand at the corner A. For the same reason, the effect of the resistance acting at B is the same as that which would be produced by applying it to the supposed straight lever at I. Therefore the power : the resistance :: I C : H C. But as I C is equal to B F and H C to A G, it follows that the power is to the resistance as B F is to A G, or as the distance of the resistance is to the distance of the power measured from a line drawn through the centre of action and parallel to the direction of the forces.

391. But the forces which act upon levers are not always parallel. Let A C B, Fig. 150, represent a lever. Let the power P (changed in its direction by a fixed pulley at D) act in the direction A D, and the resistance R, (similarly influenced by a fixed pulley at E,) in the direction B E. The simplest mode of discovering the relation of the power to the resistance under these circumstances is to produce the lines D A and E B, and to draw from the fulcrum C the lines C F and C G respectively perpendicular to D A and E B thus produced. If F C G were a bent lever, and the power were acting at F, its whole force would take effect in turning the arm F C,

because its action would be perpendicular to that arm; and for the same reason the whole resistance would take effect in turning the arm G C, if it were applied at G. As in all machines the momentum of the power is equal to the momentum of the resistance (365), and the velocity of each force is proportional to its distance from the centre of action, it is evident that the power multiplied by F C is equal to the resistance multiplied by G C, and therefore,—the power : the resistance :: C G : C F. If C G be 7 inches and C F 15 inches long, then a force of seven pounds at P would balance 15 pounds at R.

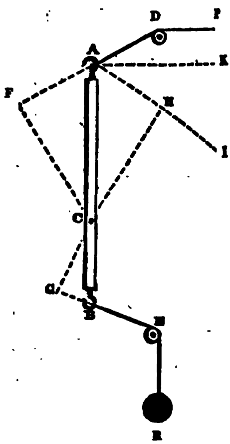

Fig. 150.

392. If the power were made to act in the direction A I instead of A D, it would be unnecessary to produce the line of direction of the force; for C H being drawn perpendicular to A I, the power would be to the resistance as C G to C H: and if the power acted in the direction A K, the force being no longer applied obliquely, the perpendicular drawn from C to the line of direction of the power would correspond with the arm C A, and we should have the following proportion— the power : the resistance : : C G : C A. Again; the principle involved in this mode of calculating is not confined to straight levers, but applies to all the forms and all the orders of this mechanical power without exception. Thus you will at once perceive that in the strongly curved lever represented in Fig. 151, where the letters have the same reference as in the last figure, the same proportion still holds good: that is; P, the power : R, the resistance : : C G : C F. After the various examples that have now been given, you are prepared to understand the following universal rule, which will enable you to estimate the *efficiency of any* lever whatever, and under all circumstances.

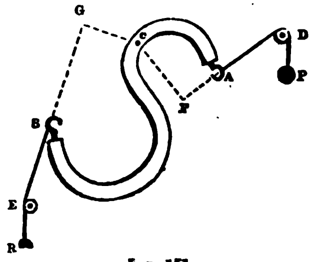

Fig. 151.

393. In every lever, the power is to the resistance as a perpendicular line drawn from the fulcrum to the line of direction of the resistance is to a perpendicular line drawn from the fulcrum to the line of direction of the power.

394. This law is applicable to the thousand little machines employed in the business of life, and we will mention a few examples, in order to awaken a habit of attention to such subjects. When a weight is carried up a stairway or any other declivity, the person who marches in rear of the body bears more than his share of the weight, and if it be carried down any descent, the person who marches in front is similarly oppressed. When a carriage descends a hill, more than half the weight falls upon the fore wheels; but when it is drawn up hill, more than half the weight presses upon the hind wheels. Let A B, Fig. 152, represent a hand-barrow upon which is placed a heavy cubic box of which the centre of gravity is at G; and let C, the middle of the length of the barrow, be perpendicularly under this centre of gravity when the barrow stands on level ground. If it be raised by two persons

Fig. 152.

of equal stature standing on the same level, the bearers will share the weight of the box equally between them; because, if we regard C as the fulcrum (387), the weight pressing on B is to the weight pressing on A, as A C is to B C; and A C is equal to B C, therefore the pressures are equal. But if the barrow be carried up a steep flight of steps, as represented in the figure, the pressure on the two bearers will be very unequal. Suppose the angular elevation of the steps to be 45°; the perpendicular dropped from the box would then fall upon the corner F of the box, and this would be the point of action of the whole weight of the box. Here, if you choose, you may consider the barrow as a lever of the third order—having its fulcrum at F. Then, as B A is to F A, so is the weight of the box to the pressure on B (329). But the universal law above laid down (393) would be equally applicable though less convenient, in this case, as you will perceive by drawing from F the line F I perpendicular to B I—the direction of the force at B—and the line F H perpendicular to A H—its direction at A. Then you will

have the following statement: As F H is to F I so i weight sustained by B to the weight sustained by A.

395. As additional instances of simple levers of the order, we may mention the common fire-poker, in which of the bars of the grate is usually the fulcrum; the pole means of which a bucket is dropped into a well and rai again, when the windlass is not employed; and the fishi rod, in which one hand of the sportsman may be said to su ply the fulcrum, the other hand the power, and the fi when caught, the resistance.

396. Scissors and most forceps are considered specime of double levers of the first order, the common fulcrum bein in the centre or axis of the pivot. Nut-crackers are simil contrivances of the second order, while the common woo shears are ranked with the third order.

397. The common wheelbarrow is a lever of the secon order, its fulcrum being in the axle of the wheel. The ba ker's barrow, Fig. 153, deserves some further notice. It i pushed before the porter, like a wheelbarrow; but if th middle of the axle of this little cart be regarded as the ful crum, the distance from this point to B may be regarded as the short arm of a lever, and that from the same point to A as its long arm. If the load be so arranged that the former with its portion of the load just balances the latter with its portion,—that is, if the centre of gravity of the whole machine be at H, directly over the centre of the axle,—the lever will resemble a steel-yard, and the slightest force will suffice to overturn it towards B. To prevent accidents, the contents are disposed so as to bring the centre of gravity nearer to the handle—say to G—and the machine is thus rendered stable.

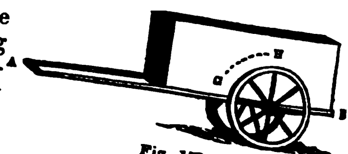

Fig. 153.

If, then, the porter raise the handle, it is only the difference between the weights of the two arms of the lever with their loads that he is compelled to lift; and he may regard the distance from A to the centre of the axle as a lever of the second order, with the resistance, consisting of the weight of the load, &c., acting at a point perpendicularly below G. It is evident, then, that the force required to raise the handle must be very small when compared with that exerted when a similar load is placed on a common wheelbarrow. Now, when the handle of this baker's bar-

is raised, the centre of gravity G is made to approach nearer to a point directly over H, along the arc G H, of which the centre is the middle point of the axle. Consequently, the point immediately below G, upon which the resistance acts, comes continually nearer to the middle of the axle; and thus, the power of the lever is continually increased, until, when G comes to H, the distance between the fulcrum and the point on which the resistance acts becomes equal to nothing, and the resistance multiplied by its lateral distance is therefore equal to nothing.—The power of the lever is then infinitely great, and the force required to sustain the resistance vanishes entirely. Thus the machine again becomes a steel-yard in equilibrium and the porter has nothing to do but to push the machine forward. The exhausting labour expended unnecessarily in lifting a large portion of the load in the common wheelbarrow under circumstances in which the principle of the baker's cart is equally applicable, may be regarded as a disgrace to our age of improvement, and an immense tax upon the public.

398. The principles laid down in several of the last paragraphs are equally applicable to all vehicles running upon two wheels, and will explain to you why horses attached to four wheeled coaches so rarely stumble in going down hill, while this accident happens so frequently to those attached to vehicles of the other class. When a single shaft-horse is aided in drawing by a very strong team, he may move with ease on level ground before a cart so heavily loaded that its weight would crush him to the ground if placed on a rapid descent; and under such circumstances, if the cart be drawn up hill, the shaft horse may be lifted bodily from the ground and overturned together with the vehicle. For this reason, when enormous weights, such as large blocks of stone, are conveyed upon any machine running upon only two wheels, they are suspended beneath the axle and left in great degree free to take the position determined by their gravity.

399. The principle of the lever may also be applied in determining the degree of stability of any object upon its base under the action of any force or combination of forces; and although this rule is not always convenient, its applicability is universal. In the four sections of bodies of divers forms, Figs. 154, 155, 156 and 157, the most important letters have the same signification. It is proposed to show the application of the law laid down in paragraph 393, to the effect of various forces, applied in different directions

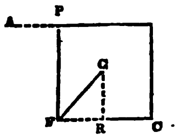

Fig. 154.

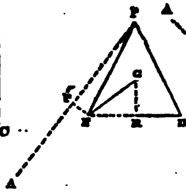

Fig. 155.

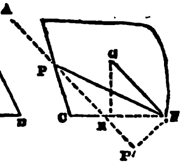

Fig. 156.

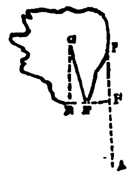

Fig. 157.

and acting at different points, for the purpose of overturning the bodies. The centre of gravity is taken as the point of action of the whole mass of the body in all these cases. In each figure P A represents the direction of the power applied; G is the centre of gravity of the body; G R is the direction of the resistance offered by the weight of the body, and F is the fulcrum or point round which the body is to be overturned. As P is the point from which the power acts, P F may be regarded as the corresponding arm of a lever; and as G is the point at which the resistance acts, G F is the corresponding arm of the lever. Now; if you draw lines from the fulcrum F, perpendicular to the lines of direction in which the power and resistance act—producing them, if necessary, for this purpose—these lines will be reciprocally proportional to the power and resistance (393). These perpendiculars are designated in all the figures except Fig. 154, *by the dotted lines* marked P F or P′ F for the power, and R F or R′ F for the resistance. In Fig. 154, which is the section of a cube or rhomb, you ascertain, by the application of the universal law of the lever, that as the power is to the resistance, so is F R to F P, because P F and G F are evidently the two arms of a bent lever. For the same reason, in Fig. 155, which is a section of a triangular prism, as the power is to the resistance, so is F R to F P′. In Fig. 156, which is the section of an irregular trapezium, the same proportion holds good, but the direction of the power, P A must be produced in order to obtain the value or dimensions of F P′ which is proportional to the resistance. In Fig. 157, which is a section of a rude rock standing on a narrow base, the proportion is similarly expressed.

400. In the common coach-wheel, when overcoming an obstacle on the road, as represented in Fig. 158, let F be the projecting corner of a stone, opposing the motion of the wheel, as drawn forward by the power acting in the direction G P. Here we have a lever G F, on which the resistance or

weight of the carriage, and the power or force of the horse are applied at the same point G, at the same distance from the centre of action, but in very different directions; for the resistance acts perpendicularly in the direction F R. From F, draw F P′ and F R′, perpendiculars to G P and G R respectively. Then, by the universal law of the lever, the power will be to the resistance as F R′ is to F P′.

Fig. 158.

401. When the perpendicular dropped from the centre of gravity, G, Fig. 159, falls upon one extremity, F, of the base, the law of the lever is equally applicable. Suppose a force to be applied at A in the direction P A; it is evident, that, in this case, the effect of the power would be represented according to the universal law, by the perpendicular line from P A to F; but the effect of the resistance cannot be represented at all; for F, the fulcrum, is in the perpendicular line G F, and the *distance* between this line and the centre of action is nothing. Therefore the resistance multiplied by this distance is nothing, and the power required to balance the resistance is nothing,—the mechanical advantage gained by the lever is infinitely great, and a breath of air would overturn the rock.

Fig. 159.

402. You perceive then that, in all cases, the nearer the line of action of the resistance approaches the fulcrum or centre of action of any lever, the greater will be the mechanical advantage and the less the distance described by the resistance. This property suggested the machine represented in Fig. 160, which is called the lever of infinite power. It is now frequently employed with various modifications, in printing, copying and other presses, in affixing seals to documents, cutting nails, stamping dies, coining, and many other operations requiring the action of great forces. F G and G B represent broad and massive plates of metal. F G is firmly secured by means of a strong pivot at F, to a beam of wood or metal forming part of a heavy frame, upon which pivot as a *fulcrum* the machine may freely move.

This plate is also attached to its fellow by a similar pivot at G, after the fashion of a door-hinge. At B, the rod C D is secured to the plate G B by another strong hinge, and drops, at C and D, through very strong cross bars of wood or metal attached to the frame. When used for impressing stamps, the bottom of this rod, armed with a suitable die E, descends upon the substance to be impressed. To one of the broad moveable plates—usually the upper one—is attached a stout bent lever A, which, when raised, increases the acuteness of the angle formed by the two plates at G and raises the rod B C D; but when it is depressed, the angle becomes more obtuse and, at length, disappears when the two hinge-like plates are brought into the same straight line. Now, the simplest mode of proving that the mechanical advantage gained by this machine may be regarded as capable of infinite increase is, to consider the arm A together with the plate F G, to which it is attached, as a single bent lever with the power acting at A in the direction P H, and the resistance at G, in the direction G R. From the fulcrum F draw the lines F A and F R′, perpendicular to the lines of direction of the power and resistance respectively. Then, by the universal law of the lever, the resistance is to the power as F A is to F R′. But, when the arm A is depressed until G is brought into the same straight line with F and B, R′ comes into that straight line also; and F R′ will become equal to nothing. The resistance will then be to the power as F A is to O: or, *no power* applied at A balances any possible resistance at G; and thus the mechanical advantage, or, as it is often called, *the purchase*, becomes infinite. Were it not for the friction of the joints, and the imperceptible distance through which the rod C D descends when the *purchase* or mechanical advantage becomes enormous, there would be no limit to the effects which might be produced in time by the repeated action of this simple contrivance. In many of its modifications it is known by the name of *the engine of oblique action* and the power is made to act upon *it in various* ways without the aid of the arm A.

Fig. 160.

403. Having now completed our remarks upon the straight and bent levers as mechanical powers, you will find very little difficulty in comprehending the action of the other simple machines, and our remarks upon them will be comparatively short.

404. *Of the Pulley.*—The pulley is in reality a simple lever. In the fixed pulley, Fig. 161, either weight, W or *w*, may be regarded as the power and the other as the resistance. Suppose the power to be *w*, it is obviously applied at P, while the resistance W acts at R. The black line P R then represents a lever of the first order, with its fulcrum or centre of action at C, which is equidistant from either extremity; and hence this lever, like a scale-beam, merely changes the direction of the force applied, without producing any mechanical advantage, and the two weights W and *w* are therefore equal.

Fig. 161.

405. Fig. 162, represents a fixed pulley secured to a beam at B, combined with a moveable pulley from which is suspended the weight or resistance R. The bent rope in the machine has one extremity permanently secured to the beam at C, and its free portion, after being doubled around the moveable pulley, re-ascends and passes over the fixed pulley. The force designed to overcome the resistance R, is usually applied at the free extremity of this rope, A. This force acts as the power on the balance or lever of the first order P′ R′ at P′, while that portion of the weight R which is supported by the portion of rope R′ P, acts as the resistance on this lever at R′. But the pulley at B being fixed, the power and resistance acting upon it are always equal (404); hence, any force applied upon this machine at A must act in full vigor at R′, and, consequently, at P. The effect of this machine upon the weight R, will therefore be the same, whether the power be applied in the downward

Fig. 162.

direction any where between A and P′, or in the upward direction any where between R and P. But very different is the effect of the moveable pulley, which forms the lever P F. Here the power is applied at P and the resistance R acts at the middle point of the lever, at only half the distance from the centre of action or fulcrum F: therefore the lever P F is one of the second order, the power is equal to but half the resistance, and a force of one pound at P or at A will balance two pounds at R; that is; the machine doubles the mechanical advantage.

406. The fact that when the machine is put in motion, the fulcrum F also moves, does not affect this constant relation of the power to the resistance; for F is a centre of revolution to the wheel P F rolling along the road F C, and consequently it advances with the same velocity and preserves the same relative position with regard to the points P and F; but the *matter* at P is always moving with twice the velocity of the *matter* at R: that is; the velocity of the power is twice as great as the velocity of the resistance. But by the law of all machines, the momenta of the power and the resistance are always equal: Therefore, in this case, the power, as before stated (405), is equal to half the resistance.

407. The truth of the same rule may be simply proved by considering that the whole resistance is equally supported on the two portions of cord which immediately support it, R′ P and C F; and hence but half the resistance acts upon R′ P and requires to be overcome by the power acting on R′ P or A P′.

408. The application of the principles laid down in the preceding paragraphs sometimes confuse the student when called upon to estimate the effects of the power in complicated combinations of moveable pulleys. In Fig. 163, though there are four moveable pulleys associated into a solid piece at A, the mechanical advantage cannot be doubled four times, —once for each moveable pulley— (405) because that would cause one pound at *w* to balance sixteen pounds at *W*: whereas the whole resistance being supported by eight portions of the cord, one-eighth of this resistance

Fig. 163.

ust rest upon the portion B (407), and being erely changed in direction, without alteration a amount, by passing over the largest fixed ulley D, it must act in the same manner on C; ence one pound at w, will only balance eight ounds at W. Here, also, you observe that if be elevated one inch, each of its eight supporting cords will be shortened one inch, and hence w will descend eight inches during the same period of time:—Therefore the velocity of the power w is eight times as great as the resistance, and, by the universal law of machinery, the effect of the power is proved as before to be eight times as great as the resistance (406). It matters not whether the moveable pulleys in such a system consist of one piece of matter—as in Fig. 163—or of separate wheels running on the same pivot—as in the common ship's block—or of wheels running on separate pivots united in one block—as in Fig. 164: the same mode of calculation obviously applies in all these cases, and the shortest mode of estimating the effect is to *multiply the amount of the power by twice the number of moveable pullies, and the result will be the amount of resistance balanced.*

Fig. 164.

409. But when the moveable pulleys united in a system act independently; that is; when each pulley is provided with its own separate cord—as in Fig. 165—the rule in paragraph 408 becomes inapplicable; because the resistance is not supported upon the different portions of the same cord. In this system, the power w, the fixed pulley A, the moveable pulley B and the cord W A B E, taken together, form exactly the apparatus represented in Fig. 162. Therefore, the effect of the power is doubled by the pulley B, and acts as a new power upon C. This pulley, with its independent cord, again doubles it in the same manner;—and D, and all subsequent members of such a series must produce a like doubling of the previous mechanical advantage, in the manner already explained in paragraph 405. Again, if W ascend one inch, each portion of the cord passing round the pulley D will be shortened one inch; consequently C will be permitted to ascend two inches. This will set free four inches of the cord passing round C, which will set free eight inches of the cord passing over A, and

this will allow w to descend through eight inches. Therefore, according to either of these modes of reasoning one pound at w will balance eight pounds at W. The most ready rule for estimating the effect of systems of this character is to *multiply the number 2 into itself as often as there are moveable pulleys in the series, and multiply the product by the amount of power employed. The last product will be the amount of resistance balanced.*

Fig. 165.

410. Here we quit the subject of the pulley, leaving you fully prepared to solve all questions in which it is concerned, by a proper application of the laws governing the lever.

411. *Of the Wheel and Axle.*—In the common lever, the power cannot be very conveniently applied, in most instances, at more than one spot at a time: and it cannot, in any case, continue to act permanently at one point while the lever is in motion; for it must follow the arm to which it is applied, and, in order to produce the greatest effect, the power and resistance must act in parallel directions. These inconveniences probably led to the contrivance of the wheel and axle, which combines all the advantages of the fixed pulley with those of the lever, and also enables the power to act at a multitude of places at the same moment and at the same mechanical advantage. Thus, in Fig. 166, if a man, standing by the side of the machine towards B, were to pull at the peg E, while another man at the side of the machine towards D, were to

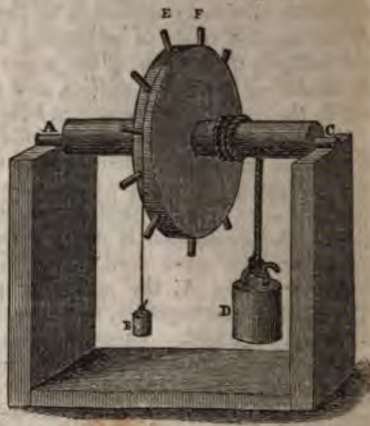

Fig. 166.

push at the peg F, there would be two nearly equal forces operating at the same time, in raising the weight D. This could not be as readily effected by means of a common lever, nor could the operation be continued for more than a short time by such means.

412. To show that the action of the wheel and axle is regulated by the universal law of the lever, it is only necessary to look at such a machine in the direction of the axle, as in Fig. 167. Suppose a straight line to be drawn from C through A to B; A being the centre of the axle, R the resistance, applied to the axle at B, and P the power, applied to the wheel at C. Then C A B is really a lever of the first order, of which A is the fulcrum, A B the short arm, and A C the long arm. Therefore R×A B=P×A C : and R : P : : A C : A B. But from this proportion we can obtain still more convenient modes of expressing the relation between the power and resistance. You perceive that A C is the radius or one-half the diameter of the wheel, and A B is the radius or one-half the diameter of the axle: and you will also remember that the circumferences of different circles are in the same proportion to each other as their diameters or their radii: Therefore R : P : : the diameter of the wheel : the diameter of the axle—or R : P : : the circumference of the wheel : the circumference of the axle. Here, then, it is plain that if you know either the radii, the circumference, or the diameter of the wheel and the axle, you can calculate the efficiency of the machine by simple division.

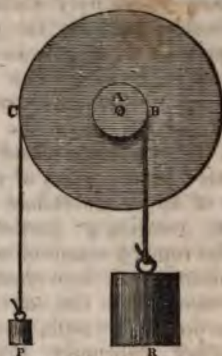

Fig. 167.

413. In the foregoing remarks we have spoken as if the power and the resistance were acting in the same plane; which is not the case in the wheel and axle; for the axle is usually of considerable length. But it is evident that the effect of any force in turning an axle depends not on the part of the surface upon which it acts, but on its distance from the middle line of the axle or the axis of revolution, in which the centres of action of all forces applied to the machine must be found, however distant their points of action may be. Therefore, in applying the law of the lever to cal-

culations involving the wheel and axle, the distance of each force from its own centre of action in the axis of revolution must be taken separately in all statements of proportion between opposing forces. This should be particularly remembered, for more than one wheel is often employed in acting upon a single axle, and several common levers are frequently used in the place of the wheel, the different forces acting at various distances from the axis; as in the ship's capstan.

414. The wheel and axle, like the lever, is capable of being indefinitely increased in power, although the contrivance made for this purpose can seldom be conveniently applied. It is seen in Fig. 168. A designates the wheel seen edgewise. The axle is not of equal diameter throughout, as in the case of the common wheel and axle; but a portion of it, B, is of larger dimensions than the remaining portion, C. The rope by means of which the resistance is overcome is wound upon the narrower portion of the axle, from its farther extremity towards the wheel. Near the junction of C with B, the rope descends, passes around a moveable pulley, D, and returning to the larger portion of the axle, is secured to it firmly, close to its junction with the wheel. The weight or other resistance to be raised, R, is applied to the pulley at D. Now, when this machine is put in motion, the rope is wound upon the larger portion of the axle, while it is wound off from the smaller portion. B therefore is constantly taking up more rope in order to raise R, while C gives off rope, as if in order to lower R. It is plain, then, that R can only be lifted by the difference between the quantity of rope given off and the quantity taken up; and this difference diminishes as C is made to approach in size more nearly to B, and disappears entirely when the two parts of the axle become equal. Suppose, then, that the circumference of A is twenty inches, that of B four inches, and that of C three inches. Under these circumstances, every revolution of the wheel A winds up four inches of rope at B,

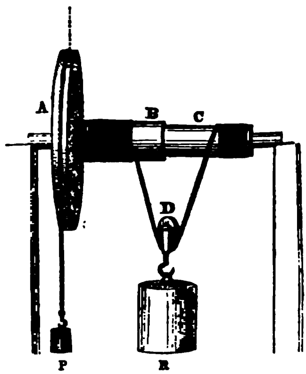

Fig. 168.

unwinds three inches at C; the loop C D B is therefore rtened one inch at each revolution. But one-half of this h is taken from the length of C D, and the other half from t of B D; so that the moveable pulley D, and with it the sistance or weight R, rises but half an inch at each re-lution of A. Now the power P moves twenty inches at ch revolution of A. That is; the velocity of the power is rty times as great as that of the resistance, and therefore $\times 40 = R \times 1$, or 1 pound at R will sustain 40 pounds at D. the difference between the circumferences of B and C were ade one-hundredth part of an inch, 1 pound at A would stain 4000 pounds at C, and the weight of an ordinary man f 150 pounds acting upon such a machine, were it made capable of bearing such enormous pressure, would balance nearly 68 tons.

415. All machinery composed of wheels furnishes us with xamples of the combination of wheels and axles, and as each nember of such combination acts upon the principle of the lever, it is easy to calculate the efficiency of the whole in the maner already prescribed for a combination of levers (388). But is usually more convenient to compare the distance through which the power travels in a given time with that through which the resistance must move in the same period of time; or, under all circumstances, the former divided by the latter ives the mechanical advantage or disadvantage under which orces act through the medium of the machine (368).

416. There are two principal modes of connecting different wheels and axles together, so that they may act as a ystem; firstly, by means f bands, aprons, or cords; r secondly, by cogs or nobs cut on the circumference of one wheel or xle and made to fit into orresponding notches in ne circumference of anoher wheel or axle.

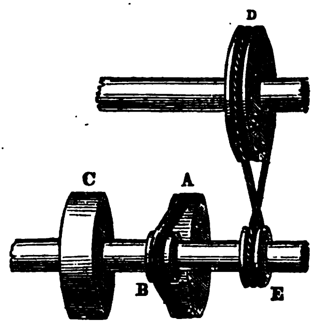

Fig. 169.

417. When such machines are associated by ands, aprons, or cords; as n Fig. 169, A, B; the acon of one part of the machine may be carried s a power *unchanged* to ny convenient distance. Thus, if A be fifty feet from B,

as long as the band or apron continues slightly stret both wheels, B must follow all the motions commun A, and will move in the same direction with the sa city. If the circumference of B be only one-fourth A, the former will revolve four times, while the revolves once, and if another wheel or roller C, of th size with A, be attached to the same axle with B, th cumference of this wheel must move four times as fa that of A. Therefore a resistance of one pound at C w balance a power of four pounds at A; and this is exactly amount of resistance which the same pound would balanc B, because the circumference of B is just one-fourth of A. Therefore the band exerts the same power at A at B, and the power remains unchanged by being transmit from one wheel and axle to another, as when transmit from one lever to another. It is only the relation betw the wheels connected together by the same axle, and wh are all compelled to revolve in the same time, whether circumference be great or small, that has any effect i creasing or diminishing the mechanical advantage o ciency of the machine. If it be desirable to rever motion when transmitted from one wheel and axle to an the band or cord must be crossed in the manner repr in the coupling of E and D, Fig. 169.

418. When wheels are associated by means of c power is transmitted unchanged in the same manner; motion is almost always reversed. In Fig. 170, the weight R may be raised by turning the handle P, in the same direction that the rope is wound on the axle G; but the direction of motion is twice reversed, in order to transmit the force applied to the rope that suspends the weight. Near the opposite extremity of the axle A B, or, as it is usually called in small machines, *the arbour*—there is a small enlargement, C, formed by a set of cogs projecting from the arbour, designed to fit and pl the intervals of similar cogs upon the margin of the w Such projections from an arbour are called *pinions*. It dent, here, that if P be compelled to revolve in either di D will be made to revolve in the opposite directio

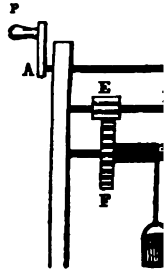

Fig. 170.

arbour of D is provided at E with a pinion in all respects similar to C, which puts in motion another wheel F. The motion of this wheel and its axle is therefore again reversed, so that they are compelled to revolve in the same direction with P.

419. In order to estimate the mechanical effect of such combination as that represented in Fig. 170, you must know the relative circumference, radius or diameter of each wheel, and the length of the crank, wince or handle. As the cogs of two wheels which act upon each other must fit together with a certain degree of accuracy as they turn, it is evident that the number of cogs on each must be proportional to their respective circumferences. You can always obtain the relative circumferences of two such wheels by counting the cogs on each, and dividing the one number by the other; but when you wish to compare the dimensions of two wheels which are not "coupled" together, the relative number of cogs furnishes no sufficient guidance: for the cogs on wheels of similar circumference may differ widely in size, and consequently in number. Thus, if the pinion C carries eight cogs and the wheel D carries twenty-four, the circumference of D must be three times that of C; but if the pinion E carries eight cogs while D has twenty-four, this does not prove that D has three times the circumference of E; for these wheels are not coupled, and the sizes of their cogs may be varied to a great extent without any inconvenience. The radius, diameter, or circumference of uncoupled wheels must therefore be obtained from actual measurement.

420. Let us now examine the relation between the power and resistance in this system of wheels and axles; and, for this purpose we will suppose the distance of the handle P from its axis of revolution in A B to be three times the radius of the pinion C:—that the diameter of D is three times that of E, and that the circumference of F is three times that of the axle G. If, in this case, a force of one pound be applied directly to P, this force will balance a resistance of three pounds at C. This amount of resistance is transmitted unchanged to D, upon which it acts as a power, and is sufficient to balance nine pounds at E. This force of nine pounds is transmitted unchanged as a power, to F, where it will balance twenty-seven pounds suspended from G. This machine, then, throwing out of the calculation the effect of friction multiplies the power twenty-seven times. The neatest way to ascertain the effect of any such combination under the action of any given power is to apply the rule

used in combinations of levers (388). Thus, in the system under notice, if the distance of P from the axis of the arbour, A B, $\times$ the radius of D, $\times$ the radius of F, be taken as one quantity, and the radius of G $\times$ the radius of E $\times$ the radius of C, as another quantity, the power will be to the resistance as the latter quantity is to the former. Any given resistance multiplied by the latter and divided by the former will give the power necessary to balance that resistance, and any given power multiplied by the former and divided by the latter will give the resistance which that power is capable of balancing.

421. The actual velocity of the circumferences of wheels that are coupled together in machinery is necessarily the same; thus C and D, Fig. 170, must move with equal actual velocities, but their angular velocities may be widely different; thus: suppose that C carries 8 cogs while D is armed with 24 cogs; also, let E have 8, and F sixteen cogs. The circumference of D will then be three times that of C, and the circumference of F twice that of E. It follows that when F and G make one revolution, E and D must make two, and C and P six revolutions. The actual velocity of the several parts of any machine is alone interested in modifying its effectiveness in overcoming resistances; but the angular velocity of a system of wheels and axles is most beautifully employed for the measurement of time in those master-pieces of human ingenuity—the clock and the watch. The unvarying vibration of a pendulum or the equally regular coil and recoil of a spiral spring is made to give motion to an *escapement* which sets free a single cog at each vibration, and determines the rapidity of the most active wheel in these machines; and by regulating the relative number of different wheels coupled together within them, it is easy to retard their revolution to any desirable extent.

422. *Of the Inclined Plane.*—The principles which govern the action of forces upon inclined planes have been very fully explained in previous sections (255), and it only remains for us to consider the most convenient mode of calculating their mechanical effects in a few of their more familiar applications.

423. Let A B C, Fig. 171, represent an inclined plane resting upon the base A C; and let R represent a resisting body, to be counterpoised by a power P, the power and resistance being connected by a cord passing over a fixed pulley at D. The usual application of the simple inclined plane is gradually to elevate or lower bodies from one level

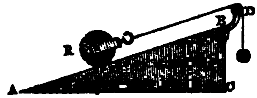

Fig. 171.

to another, by means of forces insufficient to lift them when subjected to the full force of gravity: and the power and resistance usually act in directions parallel to the oblique face of the plane, as they are made to do in the case represented in the figure, by means of the fixed pulley at D. There are many ways of estimating the relation between the power and the resistance in this case; but the most convenient method is derivable from the following consideration. The only cause of the disposition of the body R to move down the plane is the force of gravity, which acts upon the body with an energy proportional to its weight, and in a direction perpendicular to its base. But it has been already shown (254) that if the whole force of gravity acting upon such a body be represented by the length of the plane, A B, the only portion of it which causes the body to tend down the plane will be represented by the perpendicular height of the plane, B C; while the rest of the force of gravity, represented by the length of the base, A C, will be destroyed by the resistance of the plane; and this portion, acting in a direction at right angles with the surface of the plane, must also act at right angles with the direction of any force applied in the direction R D, and can have no effect in opposing such a force (220). Therefore the force required to equipoise R upon the plane A B, is to the whole force of gravity tending to urge R down the plane, (or in other words, to the weight of R) as C B, the height of the plane is to A B, its length, and R multiplied by B C is always equal to P multiplied by A B: and if A B be three times as long as B C, one pound at P will support three pounds at R.

424. Some pupils are startled or confused by perceiving in this law of the inclined plane, the semblance of an exception to the general law of the equality of momentum between the power and the resistance in all machines; for it is evident, on inspection, that P and R, Fig. 171, when in motion, must move with the same velocity under all circumstances, although the weight, and consequently the actual momentum of the latter, greatly exceeds that of the former. This difficulty disappears when we consider that action and reaction are not only equal, but *opposite*, and hence, as P acts only in opposition to that portion of the weight of R, which is represented by the height of the plane B C, while the whole weight is represented by the length of the plane A B; if the whole

weight acts in a direction perpendicular to the base of the plane, parallel to B C, this last line may be assumed as the direction in which the power and resistance really oppose each other. Now, in this direction, the momenta of the power and resistance are equal, in accordance with the general law; for if the length of the plane be equal to thrice its height, the power must move through three times the length of B C, while the resistance is elevated through once that distance, or it will advance through the distance B C in one-third the time that R will overcome gravity to the same distance.

425. As the effects of all forces acting in similar directions are governed by the same laws, any other forces acting, like gravity in the foregoing case, in directions perpendicular to the bases of inclined planes, must be subject to the following rule: *Multiply the resistance by the height of the plane, and divide the product by the length of the plane, and the result will be the power required to balance the resistance when applied in a direction parallel to the oblique surface of the plane;* or conversely, *multiply the power by the length of the plane, and divide the product by the height of the plane; and the result will be the resistance balanced by the power when applied in a direction parallel to the oblique surface of the plane.*

426. If either the resistance or the power be applied in other directions than those already specified, their effects are readily determined by the resolution of forces; and if the power act in a direction parallel to the base of the inclined plane, instead of the direction R D, Fig. 171, this resolution will show that the power will be to the resistance as the height of the plane is to the length of its base. If, then, you substitute the word *base* for the word *length*, wherever the latter occurs in the foregoing rule (425), the rule will be applicable to all cases in which power acts upon inclined planes in a direction parallel to the base, and resistance in a direction perpendicular to the base.

427. The inclined plane plays an important part in mechanics, both in the arts, and in the phenomena of nature. We see examples of it in the grading of turnpikes and railroads, in the machines by which barrels and boxes are raised into wagons when too heavy to be lifted, in the regular declension of the bottoms of mill-races designed to deliver a certain quantity of water to the mill in a given time, and to effect this purpose without rendering the current sufficiently rapid to injure the banks at any point. We see it also in the

tracks worn in the soil or rock by which timber is transmitted from mountain heights to neighbouring water courses, in the common stair-way of our residences, in the beds of rivers, and in the forms assumed by hills—of which the declivities are regulated by the power of the inclined plane, and the cohesion of the soil or rock of which they are composed; so that the geologist can often determine many details of the interior structure of a country, merely by observing the general form of its mountains and valleys.

428. *Of the Screw.*—The screw is obviously an inclined plane, winding around or within a cylinder, so as to form a helix, as you perceive, on examining Figs. 172 and 175. Its length should be measured along the middle of the plane; as it is evidently longer at the outer part of the thread or helix than along the side next to the axis. Its base must be calculated by measuring all turns which it makes around its axis, for if it could be unwound, it would form a simple inclined plane, with a base equal in length to the circumference of the screw, multiplied by the number of turns made by the thread. Here, however, as in estimating the length of the screw, we must allow for the difference in the length of the base on the side nearest the axis, and its length on the more distant side, and for this purpose we should take the mean or average between these two circumferences.

Fig. 172.

429. The height of the inclined plane of the screw is obviously the length of that part of the cylinder which is embraced by the helix. Viewed in this manner, the rules laid down for calculating the mechanical effects of the inclined plane are equally applicable to screws; but the friction engendered by this mechanical power, in most of its practical applications, is so great, and varies so much with the nature of the materials of which it is formed, that its effect may be better estimated in most cases by experiment than by theory.

430. Power is usually applied to the screw by means of the lever, as at A, Fig. 172, or by cog-wheels, which convert the cylinder into a wheel and axle; and almost invariably, this power is made to act in a direction parallel to the

base of the helix. Sometimes many levers or wheels are made to act upon the same screw at the same moment. The effect of the lever upon the screw is easily estimated by considering it as a lever of the second order, having its fulcrum in the axis of the cylinder B, Fig. 172, the resistance, being applied at a point immediately above the middle of the width of the helix, and the power at the extremity A. The effect of the wheel and axle, when the head of the screw is armed with a cog-wheel, may be estimated in the same manner.

431. As screws are almost exlusively employed in machines, for the purpose of making pressure in the direction of their axis; as in the common screw-press, Fig. 173; the resistance, as generally, acts in the opposite direction, or perpendicular to the base of the helix (C B, Fig. 172); and the power being applied in a direction parallel to the base, the effect of the screw itself (viewed independently of the lever, and friction left out of the calculation), may be estimated by the rules laid down in paragraph 426.

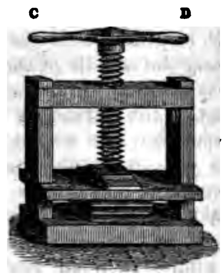

Fig. 173.

432. In Fig. 174, you are presented with a view of the differential screw-press. In this machine two screws are singularly combined, so as to be capable of almost indefinite increase of power. The larger screw B, acts in the usual way upon the frame of the press, which requires no description; but the cylinder, instead of being solid, is made hollow to receive another smaller screw A, in the manner represented in section at A, Fig. 175. When power is applied to the lever C D, the screw B advances as usual, but in so doing it embraces a continually increasing portion of A, the lower end of which advances only in proportion to the difference between the height of its own thread and that of the large screw. The resistance is applied at the lower

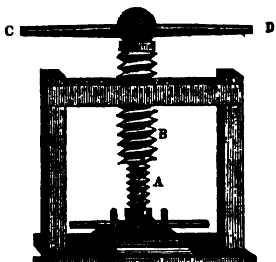

Fig. 174.

extremity of A, and hence, the velocity of this resistance is proportional not to the height of the thread of the larger or that of the smaller screw, but to the difference between these heights, which, being reducible to any desired degree, admits of almost unlimited diminution of the power required to balance any given resistance, by increasing its relative velocity.


Fig. 175.

433. *Of the Wedge.*—The usual form of the wedge is that of a solid with rectangular sides and base, and its ends presenting isosceles triangles. In this form it is usually employed in raising great weights perpendicularly upwards, or in rending the fibres of wood or splitting brittle substances. In such cases it is obvious that if we regard the resistance as acting in a direction perpendicular to the common bases of the planes, A B, the laws of the common inclined plane apply with equal force to the wedge; and if the resistance be applied at opposite points on the surface of the two planes, while the power is applied in the direction D C, the former will be moved through the distance A B while the latter moves through the distance D C; and hence; by the law of the equality of momentum between the power and the resistance, the power will be to the resistance, as the width A B is to the length C D. But the resistance is usually applied at different, and often at many points on the opposite planes; as in splitting wood (E). Here, any power acting upon the base of the wedge will cause the instrument to revolve or to endeavour to revolve around some centre of rotation determined by the many forces acting at once upon its sides, edge and base; and hence the law of the lever becomes complicated with that of the wedge, in the calculation of its mechanical effects.

Fig. 176.

434. The nature and direction of the resistance to be overcome by the wedge vary very greatly, as do those of the forces applied to this machine for the purpose of producing mechanical effects; nor is there anything more positively fixed in the form of different wedges. When these circumstances are considered in connexion with those mentioned in the last paragraph, you will not be surprised to hear that

actual experiment is generally almost the only test of the effect of wedges, when the laws of the simple inclined planes are inapplicable to the case, and that few persons, except practised mathematicians, attempt to theorize farther upon their action.

COMBINED MACHINES.

435. ***Of changes in the direction of Force in Machinery.*** —As convenience in conveying the power to the place where the resistance is to be overcome, and in causing it to act there in the right direction, is of the utmost importance in all complex machines, we will hastily glance at some of the more common modes of changing the direction of motion in machinery which have not yet been illustrated.

436. Power may be transmitted in any direction by means of the very simple contrivance represented in Fig. 177, where several wheels are bevelled at the angles required to convey the action along their different axles to the place where it should act. Thus, the band passing over the wheel A,—which may be supposed to pass through the floor of the apartment and receive its impulse from some distant source of motion—will cause the cog-wheel B to revolve. This will oblige C and D to turn in the same direction; but it will transmit the power at an angle of about 45°. D will react upon E; and here the motion being reversed, and D and E being placed at a right angle with each other, the power is conveyed along the axle of the latter to act in the same manner as if E and B had been directly coupled, without the intervention of C and D.

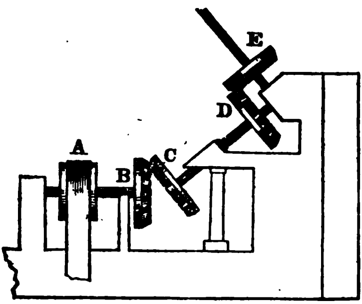

Fig. 177.

437. A very convenient mode of converting a vibratory into a circular movement, is rudely represented in Fig. 178. The beam or bar A B is suspended like a metronome (269), upon a pivot at C. It is loaded with a considerable weight at B. Human force, or that of machinery, may be employed to draw this great pendulum towards each side alternately, causing it to vibrate. F represents a toothed wheel, the axle of which is fixed to the frame of the machine, in such a

manner as not to interfere with the vibrations of A B. Two ratchet-hooks, D and E, are suspended from rivets secured to the pendulum at equal distances above and below its centre of motion C. The lower extremities of these hooks are adapted to the teeth of the wheel F, in such a manner that when B is drawn towards M, the hook E catches upon the precipitous side of one of the teeth of the wheel F, and compels this wheel to revolve from the left towards the right; while, in the meantime, the hook D is raised and drawn lightly over the inclined sides of the teeth, so as not to interrupt the motion. When B returns towards N, the hook D catches a tooth in a similar manner, and thrusts F still farther in the same direction, while E is raised and pushed over the inclined sides of the opposite teeth, to be ready to repeat its action on the wheel with the next vibration of the pendulum. Thus the alternate motion of the pendulum is made to produce a constant circular motion of the wheel.

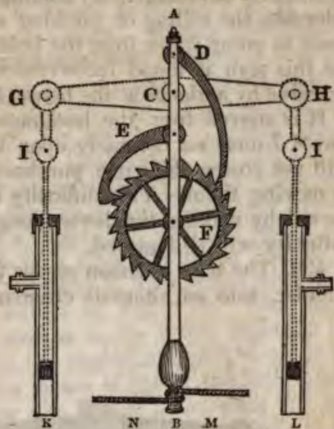

Fig. 178.

438. If, in the same figure, the hooks D and E and the wheel F be removed from the apparatus, and their place supplied by a lever or beam G H, suspended at the same point C, and there firmly connected with the pendulum A B, it is evident that the former must vibrate horizontally whenever the latter is made to vibrate in the upright position. Now, suppose that two shorter levers, G I and H I, are suspended from the extremities of G H, and that each of these is secured by a hinge-joint at I, to the rod of a pump, K, L. Then, whenever B is drawn alternately from side to side, G and H must play up and down with an alternate circular motion, carrying with them the levers G I and H I, and the pump-rods attached to them; thus working the pumps. In this case an alternate circular motion is converted into a rectilinear motion. Pumps upon this construction are advantageous under certain *circumstances*; for, by affixing two ropes to a

ring placed upon the extremity of the pendulum at B, any number of men may be employed in working them at the same mechanical advantage. By making the weight of B very considerable, the rolling or pitching of a vessel at sea may be made to pump water from the hold without the aid of hands; but this plan is found inconvenient in practice. You will perceive by a glance at the figure, that the moment the beam G H is moved from the horizontal position, the levers G I and H I must act obliquely upon the pump-rods, and hence will not possess the same purchase or mechanical advantage in moving them. This difficulty is diminished, but not removed by making the levers longer, because their angle of obliquity will be lessened.

439. The most common means for converting a continued circular, into an alternate circular or rectilinear motion, or

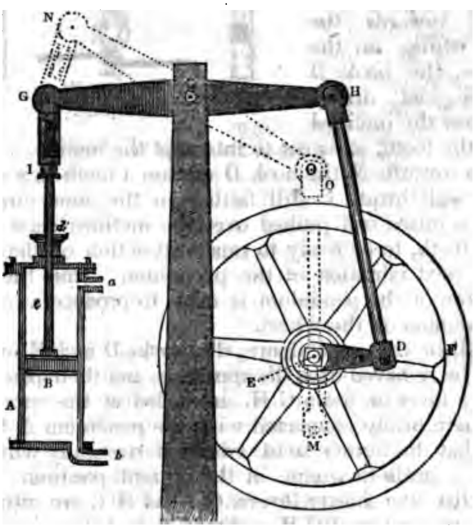

Fig. 179.

the reverse, is the *crank*. We will study its action upon some of the first members of the system of machinery called the *steam-engine*. A, Fig. 179, represents the cylinder in section; G H the main-beam; H D the pitman, often called the connecting-rod; E D the crank, and F the fly-wheel. The *cylinder* is a hollow vessel of strong iron, provided with caps

or covers of the same material at each extremity, and completely enclosed on all sides, except in a few places. Near the top, a small tube, *a*, penetrates it to admit steam when required. A similar tube, *b*, makes its entrance at or near the bottom, to perform the same office. Within the cylinder is placed the piston B, a cylindrical body, formed of metallic plates and packing, designed to be pushed alternately from one end of the cylinder to the other by the pressure of the steam. To this is attached the piston-rod *e*, which passes through a circular canal in the thick cap of the cylinder *d*, and fits it so closely as to be air-tight, when the little cup placed on the summit of the cap is filled with oil or grease. This rod is connected by a hinge-joint with one end of the main-beam G H, by means of a strong swinging lever G I: these parts corresponding precisely in their action with those designated by the same letters in Fig. 178. The piston and its rod communicate motion to the whole engine in the following manner. When the engine is started, steam is admitted into the cylinder by means of one of the little pipes; and let us suppose the pipe *a* to be first selected for this purpose. The force of the steam drives the piston nearly to the bottom of the cylinder, the air contained below being expelled by a pipe not seen in this figure. During this operation, the pipe *b* is closed by a part of the machinery called a *valve*, the nature of which you will comprehend hereafter; but the moment the piston has descended to the proper extent, the pipe for the escape of air from the lower part of the cylinder, as well as the pipe *a*, is closed: then steam is admitted below the piston, which drives it nearly to the top of the cylinder; the steam above the piston escaping, as the air escaped from below during the preceding stroke. B having reached its proper height, the upper escape-pipe and the lower admission-pipe *b* are closed, while the lower escape and the upper admission-pipe *a* are opened, to bring the piston down again. The piston-rod *e* is thus forced up and down with an alternate rectilinear motion, compelling the lever G I to rise and fall with it. This lever hangs perpendicularly when G H is horizontal, that is; at the middle of each piston stroke; but when the beam is thrust upward or drawn downward, as it must be at the end of each alternate stroke of the piston, the beam assumes an oblique position; as represented by the dotted figure N O; and, consequently, the lever G I also assumes the oblique position N G, and acts at considerably less mechanical advantage. Here you see the alternate rectilinear motion of the piston converted

into an alternate circular motion both in the lever and the beam.

440. From the opposite end of the beam, H, the strong connecting-rod or pitman hangs suspended upon a pivot, allowing it to swing freely. The lower extremity of this rod, D, is attached to a crank or handle, E D, which turns the axle of the great fly-wheel, F. The axle of F also gives motion to the rest of the machinery; but of this it is unnecessary to speak. As H descends to O, the arm H D becomes more and more nearly perpendicular, and consequently approaches E, which is the centre of its action on the wheel F; and, by the law that the effect of all forces is greater in proportion to their distance from the centre of action, the power of the beam, in turning the wheel F, is continually diminished until D reaches M, when the beam loses all its power in causing F to revolve. Here the machine would stop, and no force of steam could cause it to move any farther, were it not that the momentum of a moving body cannot be instantly destroyed. Before H D reaches the centre of action at E, it has had time to communicate very considerable momentum to the large and heavy wheel F, which, therefore, continues to turn by its own momentum, sweeping the crank and the arm H D past the point M. Thus, when the great beam begins to rise again, the crank once more becomes a lever, and continues the motion of the wheel until H reaches its highest point, when the arm H D again loses all its mechanical advantage in turning the crank; and the machine would be just as effectually stopped at this moment, were it not for the momentum of F, which again carries the crank beyond this critical position, and thus enables the rectilinear motion of the piston to be converted into continued circular motion in the fly-wheel. It is hardly necessary to tell you that this change may be reversed with equal facility; for, if F were a water-wheel, set in motion by a stream, it is evident that the crank would cause the arm H D and the great beam to move in the same manner; so that if A were a pump, instead of the cylinder of a steam-engine, its pump-rod *e* would receive an alternate rectilinear motion from the continued circular motion of F.

441. Though modern art has complicated the modes of changing the direction of force and motion to an incalculable extent, the principles and the examples which have now been given will enable you to comprehend the mere mechanical operation of almost any complex machine, when the effects of friction, aerial resistance, &c., are neglected.

442. The accurate calculation of the effect of the different parts of such contrivances may demand, in many cases, far higher mathematical acquirements than you at present possess; but, if we have succeeded in securing your attention, you will no longer be lost in wonder, vexed by ungratified curiosity, disgraced by stupid indifference, or agitated with needless dread, upon entering a woollen or cotton-factory, a paper-mill, printing office, or steamboat. These noble monuments of human intelligence—these magnificent machines for the erection of respectability and happiness upon their only legitimate and rational foundation, industry, will no longer appear to you as books written in an unknown tongue—things placed altogether beyond your comprehension—but you will find in them the proofs of a thousand principles of useful and of daily application. Are you a boy, and would you be a farmer, and fell a tree, erect a barn, guide a plough, or break a horse, with safety to life, limb, and property?—Study mechanics! Would you be a seaman or a merchant, and properly load a vessel, store your goods, or choose a porter, or a wagoner who understands his business?—Study mechanics! Would you be a physician, and set a fractured limb, or handle a suffering patient without torture?—Study mechanics! Would you be a lawyer, and plead the cause of a farmer, a seaman, a merchant, or a physician or his patient?—Then study mechanics! Are you a girl, and would you rise from an humble and subordinate position to one of domestic command and importance by the intelligent performance of household duties?—Still, we say, study mechanics! Is your situation so fortunate as to secure you the inheritance of an establishment of moderate means—the almost universal position of the well-educated American woman? If you wish to be able to put up or take down a suit of curtains, without falling from the high steps, or the chair ill balanced on the table-top; if you would tie up your Venetian blinds without loosening the pins; set your table without straining the hinges; place glass or china upon a marble slab, without breaking the brittle and elastic article; put up a bedstead without overtasking your own strength or that of your female dependants,—for whose physical as well as moral well-being you are responsible to a higher power, that will not be paid by weekly wages or satisfied with pecuniary damages—even if you would merely secure that these things are properly done by others—again, we say, study mechanics! If, in fine, you would avoid becoming that which, next to the fop, is the most ridiculous in youth

and the most miserable in age—a useless *fine lady*, that has nothing to do, and cannot think—who is a mere cumbersome article in the furniture of a family, and too often a curse to everything that she is bound to protect, condemned by Heaven for her sins of omission almost as completely as the worst of her sex is condemned by the world for open crime, —if you would avoid all this, study mechanics, and shun that terrible punishment of a youth of unobservant folly, *an old age of bitter regret for opportunities neglected.* But moral lectures, in a scientific school-book, should be but a holiday amusement. Let us pursue our labours.

443. *Means of regulating the velocity of machinery.*—Almost all complex machines are so constructed that the moving power acts with various advantage at different moments of time; as when a crank is employed to turn a wheel; consequently, the velocity of a machine and the quantity of resistance which it is capable of overcoming are also varying continually. Now, it is of the utmost importance that the action of any apparatus should be rendered as uniform as possible, in order to economize moving power, which is always limited and expensive. For this purpose the fly-wheel is added in almost all machines of considerable size. It is a heavy mass of metal, such as that seen at F, in the last figure, connected with some part of the apparatus near the source of the motion; and frequently the connexion is made by means of powerful cog-wheels and pinions which multiply its velocity many times, and thus, by increasing its momentum, give it a high degree of power without an extravagant weight. The sole office of this wheel is to assist the moving power when acting at the least mechanical advantage, by reserving a portion of the momentum which it acquires when the effect of the moving force is greatest. This it does in the following manner:—When the machine is first set in motion, it would very soon acquire its greatest velocity if it were not for the inertia of the fly-wheel, which is overcome slowly, and thus allows the other and more delicate parts of the apparatus to acquire their proper velocity gradually and safely, where otherwise they might be shattered by the suddenness of the force applied. But, by the continued operation of the moving force, the fly-wheel acquires its proper share of the mean velocity of the whole system, and, being heavy, retains its momentum with great obstinacy.

444. When the stationary steam-engine, figure 179, is first set in motion, the crank is acting at the greatest advan-

tage, yet the motion is very slow, because the fly-wheel F opposes the change of its condition, and yields with reluctance. Before the crank has descended to M, however, this wheel has acquired momentum enough to sweep past that point, reacting upon the great beam, and forcing down the piston to a sufficient extent to allow the steam to act upon the crank to advantage once more. Additional momentum is acquired by F, before the crank points perpendicularly towards the beam again, and this critical point is passed with still greater facility and speed. Thus the fly-wheel constantly increases in velocity till the machine is under full way. It appears, then, that a fly-wheel takes from the moving power a certain share of its force when at the greatest, and gives out again as much of this portion as is necessary, when the force of the moving power is least. This effect is sufficient to render the motion of the machine nearly equal at all times; but, even in the most perfect contrivances, where the crank is used, it is impossible to render the action of the force absolutely uniform. Thus, in the steamboat, close attention to the sound of the paddles will convince you that twice during each revolution, their velocity reaches its greatest height, and twice it sinks to the lowest point. The same thing is true wherever the nature of motion is changed from the alternate to the continued character, in any direction; because such is the imperfection of human art, that there is always a short pause at the end of each alternate motion, during which the moving force loses its action altogether. Were it not, therefore, that motion already acquired cannot be instantly stopped, very few mechanical inventions could be made practically useful.

445. The resistance to be overcome by a machine is usually varied from time to time, and consequently the velocity varies under the action of the same moving force. Thus, in grist-mills, when the hoppers are full of grain, the stones are prevented from moving with undue velocity by the friction of the grain that is crushed between them, which prevents the force of the water from moving the water-wheel with so much speed as it would otherwise acquire; but when the supply of grain is suspended, and the hopper "runs low," the wheels turn much more rapidly, and, by their quick jarring, arouse the attention of the miller, informing him that it is necessary to replenish the supply, lest the stones should grind each other smooth instead of manufacturing flour. The fly-wheel, by its inertia, prevents these changes from taking place so suddenly as to endanger the machine. If the pad-

dles of a long steamboat, running "dead before the wind," were quickly raised above the water on both sides, by two heavy swells raising the bow and stern while the middle of the boat occupied for the moment "the trough of the sea," the absence of a fly-wheel would almost insure the shooting of the piston through the head or bottom of the cylinder, like a ball from a cannon—an accident that has actually happened. This danger past, the paddles would acquire such speed by the time the retreating wave allowed them once more to strike the water, that they might be dashed to pieces by the blow.

446. The locomotive engine is one of the few heavy machines requiring no fly-wheel or substitute therefor; for, in this apparatus, the inertia of the whole engine, when in motion, added to that of the train, if attached, prevents any very sudden change of velocity. But, when such an engine is passing over a very smooth place on the rails, where the friction of the road upon the running wheels is diminished, you find, from the quick spitting of the steam and the unavailing rapidity of the wheels, that the absence of a fly-wheel as a regulator is sufficiently perceptible.

447. The moving power of a machine may vary, from time to time, as well as the resistance. Thus, if a floodgate be opened to admit the water to the water-wheel of a mill at noon, while the miller goes to dinner, a sudden shower may swell the race, and thus give to the machinery, the fly-wheel included, a velocity that may spoil the produce of the mill; and in steam-works, the going down of the fire during the absence of the engineer may seriously retard the work. To prevent such disasters, a beautiful contrivance has been invented, to regulate the supply of steam or water, without the immediate agency of man. Fig. 180 represents the essential parts of this apparatus. You see in it a long arbour or axle, A, playing, by means of its sharpened extremities, in little cups or depressions sunk into iron supports placed

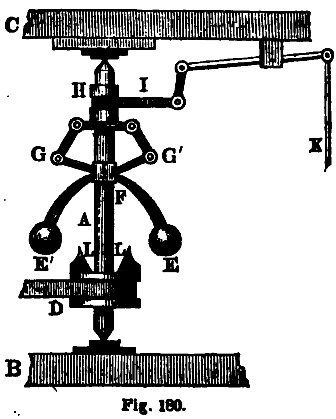

Fig. 180.

upon the beams or other wood-work B and C. Upon the lower part of this arbour is secured a small, smooth wheel, which is turned by a band, D, connected with the machine that the apparatus is designed to regulate. The middle part of the arbour, at F, is squared, and a mortise or window being cut through it from side to side, two bent levers, G E and G′E′, are made to cross each other at the middle point of the mortise, and are there secured by a pivot passing through them, but permitting motion, like the blades of a pair of scissors. The lower extremities of these levers are armed each with a heavy ball of metal, E E′, and, to their upper extremities, two shorter levers are attached, resembling, in their hinge-like motion, that which connects the piston-rod of the stationary high-pressure steam-engine with the main-beam of that machine (439). These shorter levers, in their turn, are attached to a sliding, cylindrical piece of metal, H, which plays freely up and down the arbour A. The cylindrical sliding-piece is grooved near the middle, to receive the extremity of a short piece of wood or metal, I, projecting at right angles from the arbour, and embracing the narrow part of the cylindrical sliding-piece without pressing upon it; so that the former may remain at rest while the latter piece is revolving with the axle. The other extremity of I is connected with a system of levers which will be understood at once by consulting the figure, and which terminate in the rod K. This rod is connected with a valve which admits more or less steam into the main pipe that supplies the cylinder of the steam-engine, or with the flood-gate supplying the water-wheel of a mill with water. When the rod is raised, less steam or water is admitted to the machine, and when it is depressed, more of the moving force is allowed to come into action. Let us, then, examine the mode in which this contrivance tends to equalize the force exerted by the moving power, when accidental causes increase or diminish its energy.

448. When the machine is put in motion, the band D, acting on its appropriate wheel, causes the arbour A to revolve; and the two levers G E, G′E′, together with the smaller levers and the cylindrical sliding-piece H, are compelled to revolve with it, by the pivot which attaches the greater levers to the square part of the arbour at F. But I is not thus compelled to assume a circular movement; for it permits the sliding-piece to revolve freely within the hole made in this cross-piece for its accommodation. Now, the bodies E and E′ being made heavier than the rest of this part of the

apparatus, they acquire a greater degree of centrifugal force, and consequently fly off from the arbour or from the notches in the little props L L, upon which they repose when the machine is at rest. This separation of the two balls depresses the opposite extremities of the levers, at G and G', and drags downwards the sliding cylinder H. This, in its turn, also drags downward, or depresses the commencement of the lever I, elevates its opposite extremity with the rod K, and partially closes the steam-valve or the floodgate. Thus, the moving power is made to curtail the supply of its own force to the machine, and, when it becomes excessive, controls its violence most effectually. If, on the contrary, the moving force begins to decline, the revolving balls approach each other, the sliding-piece is forced upwards, the rod K is depressed, more steam or water is allowed to act, the activity of the machine is preserved without material diminution, until, when the revolving balls sink into the props or crutches L L, the steampipe or the floodgate is closed, and the apparatus stops. It is evident that this contrivance supplies, in great degree, the duty of a fly-wheel, and with greater economy, because it contains less matter to be moved. But in regulating great machines, both contrivances are often advisable assistants.

Here we will close the subject of the application of mechanical laws to solid bodies, and proceed to consider their influence over matter in other states or conditions.

CHAPTER III.

PHENOMENA OF FLUIDS.

449. All the great laws that relate to the mechanical action of solids are equally applicable to that of fluids; but the wide difference in the condition of the particles of these two classes of bodies, in relation to their mobility among each other, produces phenomena apparently so various that different names have been adopted to distinguish the several branches of science which treat of the motions and force of solids, liquids, and gases or airs. Different writers have given such various, and often contradictory definitions of these terms, that it becomes necessary for each author to define them for himself, if he wishes to convey clear ideas.

450. *Physics* is the name of that science which treats of the structure, properties, and actions of material things. Together with metaphysics, which professes to treat of the properties and actions of the mind, it embraces the entire circle of human science. It is divided into numerous departments, of which we are only required at present to define the following.

451. *Dynamics* is the name of that branch of physical science which treats of the doctrine of power or force. It is applied by many, through a false construction, to the doctrine of power or force, as it affects solids only. Through a still worse error, many others confine its application to the doctrine of power or force, as displayed by solid bodies when in motion.

452. *Statics* is the name of that subdivision of dynamics which treats of physical power or force when it preserves bodies in a state of relative rest; and its fundamental principles have been developed in the earlier part of this volume.

453. *Mechanics* is the name of that division of dynamics which treats of physical power or force when it creates or changes the direction of, the relative motions of bodies. The first principles of mechanics, so far as they are admissible in this work, have been already discussed.

454. No term has been invented to designate the branch of science which treats of the application of the laws of dynamics to fluids in general, but several are in constant use to express subdivisions of this branch.

455. *Hydrostatics* is the name of that secondary subdivision of dynamics which treats of the peculiar phenomena produced by physical power or force, as witnessed in *liquids* when in a state of rest or equilibrium or relative rest. To define the word by the shortest possible phrase—*Hydrostatics is the statics of liquids.*

456. *Hydraulics* is the name of that secondary subdivision of dynamics which treats of the peculiar phenomena produced by physical power or force, as witnessed in liquids when in a state of relative motion: that is; *hydraulics is the mechanics of liquids.*

457. All the peculiarities observed in the action of dynamic forces upon liquids, so far as they fall within the scope of hydrostatics and hydraulics,* result from one single property

* The term hydrodynamics, which should include these two subdivisions of physical science, has been so perversely appropriated to the science of fluids in motion exclusively, that the author is compelled reluctantly to dismiss it altogether, in a school-book.

of liquids; namely; the free motion of their particles among themselves, in consequence of their peculiar arrangement and mode of cohesion. The laws which govern motion and rest are precisely the same in all respects, whatever may be the state or condition of the body acted upon by dynamic force. Hence, if we were perfectly acquainted with the laws of attraction and the forms of atoms and molecules, we should be able to foretell all the dynamic phenomena that fluids can display, from our knowledge of the effects of physical force upon solids, even without resorting to special experiments; for a liquid body is but a collection of relatively moveable little bodies (molecules), and a solid is a collection of relatively fixed, though otherwise similar bodies.

458. *Pneumatics* is the name of that subdivision of dynamics which treats of the peculiar phenomena produced by physical power or force, as witnessed in airs or gases, whether they be relatively in motion or at rest. This term may therefore be defined—*the statics and mechanics of airs or gases.* The terms *aero-dynamics* and *aerostatics* are occasionally used to express the dynamics and statics of air, gas, or aeriform fluids.

459. All the peculiarities observed in the action of dynamic forces upon gases, result from two properties of matter in the gaseous state: 1st, the mobility of the particles among themselves, in which they resemble liquids; and, 2d, the great mutual repulsion of their particles, by means of which they fly apart to an unknown extent, when freed from the action of all forces that tend to press them together—a peculiarity of which you will form more correct notions hereafter. Were we fully acquainted with all the laws of molecular attraction and repulsion, we should be able to foretell all the results of pneumatics from our previous knowledge of the dynamics of solid bodies, without the necessity of farther experiment. Therefore, in studying the subjects discussed in the present portion of this volume, you should remember that you are not studying new laws, but merely the results of the laws with which you are already acquainted, when modified in their application by the peculiar condition of the molecules of the matter in liquids and gases.

460. It will also preserve you from many mistakes to remember that the subdivisions of dynamics, like all systematic arrangements of physical science or knowledge, are purely *artificial*, and founded upon approximations to truth rather than truth itself. Thus, as you have just been told, all the dynamic peculiarities of liquids result from the free

motions of the particles among themselves: but, as no body in nature is perfectly hard, the particles of all bodies, however solid, must be capable of moving upon each other, to a certain extent, like those of a liquid; and it is only because the peculiar mode in which the molecules of solids interlock with each other, owing to their near approach, or because the balance between their mutual attractions and repulsions is not yet fully understood, that we are unable to discover in their motions clear traces of all the phenomena displayed in liquids. It is even impossible to point out, in the present state of our knowledge, the exact point where solidity ceases and liquidity begins; for different liquids display every degree of fluidity, from the most delicate ether, which may be regarded as almost a gas, to the thickest molasses, which is almost solid, and gradually becomes entirely so, by mere evaporation; thus connecting the fluids with lead and other malleable metals, through which we may trace the gradual diminution of the same property, up to iridium, the sapphire and the diamond, the hardest of known substances. Again; all the dynamic peculiarities of airs or gases which distinguish them from fluids of the liquid character, result from "the great mutual repulsion of their particles," &c. (458). On this account, the particles of gases can be driven nearer together by pressure, but immediately recover their former position upon the removal of that pressure. Thus; if you tread upon a tight bladder full of air, the air is compressed into much smaller space, and when your foot is removed, it expands, and becomes as bulky as before. Formerly, liquids were called incompressible fluids, because it was thought that water, the most common of them all, could not be compressed; but it has since been ascertained that they may be compressed by very powerful forces. Even a pressure of about sixteen pounds to the square inch of the surface reduces alcohol by about 0.000,066 of its bulk,—water, to about 0.000,046,—and mercury, by about 0.000,003. By enormous forces, water has been apparently reduced by one-twelfth part of its bulk. When thus compressed, a liquid instantly resumes its original dimensions on the removal of the pressure; but it cannot expand permanently beyond the point at which the mutual attraction and repulsion of the molecules balance each other. Within this limit, however, the particles of water are repelled from each other as surely as those of a gas. There is every reason to believe that the phenomena of elasticity in solids are owing to the same cause; and hence we may safely infer that the

mutual repulsion of the particles of gases differ only in degree, and not in nature, from that observed in solids and liquids.

461. It is very true that we discover, and can measure the extent of this repulsion, both in solids and liquids, while we perceive no limit to its action in airs and gases; but this by no means proves that no such limits exist. If caloric—the presence of a certain quantity of which is necessary to bring any kind of matter into the gaseous state—be really a material substance, it is quite probable that the distance to which the molecules of gas can be separated by repulsion may depend rather upon some unknown law of this imponderable agent than upon any property of the molecules themselves. Be this as it may; there is reason to believe that the atmosphere we breathe has its limits, and does not exist throughout all space, as many suppose. We know that many vast collections of vapour, much lighter than air, exist thoughout the heavens;* forming worlds of gas, through which the stars shine brightly; yet each of these revolves as a sun or planet around the centre of gravity of its own system as regularly as our earth and solar planets. These are entire bodies of gaseous fluid. Our atmosphere would probably resemble them, could it be viewed from the moon. Many comets appear to be of the same nature, and if the order of creation should permit one of these bodies to come in violent contact with our atmosphere, there is nothing unnatural in the supposition that it might rebound therefrom, like a soap-bubble from the sleeve of a cloth coat, a falling rain-drop from the leaf of a flower, an ivory ball from the cushion of a billiard table, or a cannon-bullet or pebble from the surface of water.

462. One of the most remarkable seeming peculiarities of gases, is their increasing *tenuity*, *rarity*, or thinness, as they recede from a centre of gravitation. Thus, our atmosphere becomes more and more rare as we ascend a mountain or rise in a balloon, until, at length, it becomes too thin to support animal life. But this is not really peculiar to the gases. The only reason why the lower portion of the atmosphere is more dense than the upper portion is that it has to support the weight of the upper portion, which acts upon it as a compressing force. Even were the earth removed, and the atmosphere left alone in its place, this same force would continue in action, and the same result would be observed, though in less degree, because the molecules of air would

* See Kendall's Uranography.

then gravitate towards a common centre, as before, and the upper would still press upon the lower portions. Since it has become known, by actual experiment, that fluids are compressible, it is generally acknowledged that an analogous gradation of rarefaction occurs in liquids similarly circumstanced. Thus, the water at the surface of the sea is less dense than that which occupies its depths, and that of a mountain lake must necessarily be rarer than that of a river of the plains; though, in the latter case, the difference is too slight to be taken into our usual dynamic calculations. By the same rule, the central portions of a solid must be more dense than the surface, for the force which causes the molecules to gravitate towards the centre of gravity of the body exists here also, and the molecules never being in absolute contact, this force must produce some effect, although it is altogether too small ever to become a subject of calculation, unless in reasoning upon the nucleus of a comet or nebula, a planet or a sun. The rapid rarefaction of water very near its surface, where the pressure approaches to nothing, has induced, in Laplace, and some more recent German mathematicians, an attempt to explain some of the most difficult problems connected with capillary attraction.

463. Parts of the foregoing reasoning may be too deep for most of our young readers, but they will comprehend enough of the argument to enter upon the three succeeding chapters much more understandingly.

CHAPTER IV.

HYDROSTATICS.

464. As the cause of the peculiarities observed in the action of forces upon fluid bodies is to be sought, not in any peculiar condition of these bodies viewed as masses of matter, but in that of their molecules, let us inquire more fully in what this peculiarity consists. The molecules of solids cannot be made to move *perceptibly* upon each other without the exertion of very considerable force, in consequence of their arrangement and their very strong cohesion; but those of liquids are so arranged as to change their place with very great facility under the action of exceedingly small forces. If you even breathe upon the surface of water, the blows

of the invisible particles of air discharged from your mouth with moderate velocity are sufficiently powerful to lash it into waves.

465. This mobility cannot be attributed to the form of the molecules, because, when water is frozen into ice, it becomes a solid, and we have no reason to believe that the form of its particles is changed thereby; moreover, all solid bodies are convertible into liquids by sufficient heat. Nor can we attribute the mobility entirely to the diminution of cohesion, for some liquids possess very obvious cohesion and some solids but little. That friction should be much lessened by changing a body from the solid to the fluid form is quite intelligible; for, in the latter state, every indefinitely small molecule acts as a little friction wheel (244) whenever motion is communicated to it; but that friction between the molecules of the most perfect known fluids still exists, and that without it the world would be scarcely habitable, has been already shown (193).

466. The importance of the cohesion of liquids appears in our remarks upon capillary attraction, and that of their friction will be acknowledged when we arrive at that part of our narrative which treats of the motions of liquids. But the forces required to overcome both these causes of resistance are so slight, when the motions between the particles are very slow, that the resistance becomes incalculably small in the more perfect liquids, and may be entirely neglected. It has no perceptible effect upon any question connected with the mere equilibrium of liquids.

467. The particles of any body in the liquid state are farther apart than those of the same body in a solid state, and even in the latter condition, they are not in contact. It is, therefore, admissible, for purposes of illustration, to represent the molecules of a fluid body by dots or small figures of any form, removed to a short distance from each other. Therefore, let Fig. 181 represent a section of a basin containing water, and let the little globules in the figure be the molecules of the liquid as seen in section.

468. The surface of the liquid at rest in this basin, like that of a lake in very calm weather, is level, except near the edges. But every particle is drawn directly downward by gravity with a force proportional to its weight. Let us choose any one particle on the surface, as *A* in the figure. The weight

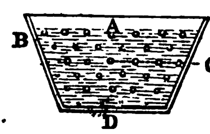

Fig. 181.

of this particle would cause it to descend if it were not supported. But it does not descend, for the liquid is at rest. By what force, then, is it supported? Certainly not by cohesion and friction, for the slightest force, a mere breath, would cause it to move freely among the other particles. The lateral pressure of the particles all around it will obviously keep it from moving towards the side of the basin in any direction, but there is nothing to prevent it from descending towards the bottom, except the upward pressure of the particles beneath it. This upward pressure is equal to the weight of the particle; for if it were greater than the weight, A would be driven upwards above the surface, and if it were less than the weight, A would sink beneath the surface. Let us now choose a molecule lower down in the liquid, such as C in the figure. If the liquid be at rest, C must also be at rest. But it is urged downwards both by its own weight and by that of the two particles above. Thus the force that presses it downwards is three times as great as that acting upon A at the surface, *because C is three times as deep in the liquid.* Under this force C would necessarily descend if unsupported by an equal pressure from below upwards, exerted by the particles beneath it. But it does not descend. Therefore it is supported by an upward pressure three times as great as that which supports A at the surface; and it is thus supported, *because it is three times as deep in the liquid.* If C were urged by any force acting in any other direction, it would move in that direction, unless the pressure of the particles in the opposite direction were equal to that force. But when a liquid stands at rest in an open vessel, all its molecules are at rest whatever may be their depth; therefore every molecule in a liquid is subjected to a pressure resulting from the weight of the liquid acting upon it equally in all directions, and as action and reaction are always equal, it must also act equally in all directions upon the particles around it. Here, then, you perceive the only peculiarity in the condition of the molecules of a liquid which modify the effects of forces upon it: and, but for this, all the laws of mechanics could be applied in the same manner to solids and to fluids. The manner in which their application is influenced by this peculiarity, will appear in the sequel, when we explain the importance of the following law of liquid pressure in solving some of the most familiar questions in hydrostatics. This law is but a short mode of expressing the facts that have just been proved. It should be committed to memory.

469. The pressure of liquids acts equally in all directions.

470. If liquids were altogether incompressible by force, that is, if their molecules could not be pressed nearer together by any mechanical force, however great, it is evident that the number of particles supported by any one molecule would be proportional to its depth below the surface; (see C, Fig. 181), or in other words, the pressure would increase directly as the depth. It has been proved experimentally, that all fluids are to a certain extent elastic and compressible; so that even the most refractory liquids; such as alcohol, mercury and water, can be squeezed into smaller space by tremendous forces. The number of molecules in a unit of solid measure—a cubic inch, for instance—must, therefore, increase as the depth of the liquid increases, and, consequently, the pressure, which depends on the weight of the superincumbent particles, must increase faster than the depth. But, as no force which can be commanded by man is sufficient to produce any very considerable change of density in water and most other liquids, the following law, which should also be committed to memory, is sufficiently near the truth for all practical purposes.

471. The pressure of liquids increases directly as their depth.

472. Let A B C D, Fig. 182, represent a section of an upright cubic vessel completely filled with water. It is evident that the bottom of this vessel must bear the pressure of the whole weight of water in the vessel, because the gravity of all the particles tends directly downwards against it; and this pressure will be proportional to the depth of the water and the size of the bottom. On comparing the pressure upon the bottoms of cubic vessels of different sizes, it will, therefore, be found proportional to the depth of the liquid multiplied by the area of the bottom; and the same thing is obviously true with regard to upright vessels of a prismatic or cylindrical figure.

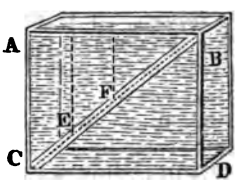

Fig. 182.

473. Now, let us suppose a light and thin board of some kind of wood which is just as heavy as water, to be laid diagonally across the vessel A B C D, in the manner represented in outline in Fig. 182; and let this board be so narrow as to permit the water to flow freely round its edges. If we select any point on the surface of this board, such as E or F, it is evident that the water must press with equal force both above and below this point (leaving out of the cal-

culation the thickness of the board); and hence, the board must press downward upon the liquid in the space B C D, as powerfully as the water in B C A, would do if the board were removed; and the pressure on the bottom of the vessel will also continue unchanged. Let us next suppose that the edges of the board are secured to the sides of the vessel by means of putty, so as to cut off all communication between B C A and B C D. This cannot make the slightest difference in the upward pressure of the fluid contained in B C D; Therefore the board will continue to press upon it with the same force as before, nor will the pressure upon the bottom be varied in the least: for it matters not whether this pressure be produced by the reaction of the board or by the weight of the water above it, the one force being exactly equal to the other. But when all communication between the upper and lower chamber is prevented, the weight of the water in B C A, can have no influence in increasing the pressure on the bottom, because the board prevents it from acting. Then, let B C A be emptied entirely, and still the water below B C will continue to press upon the bottom of the vessel and upon the under surface of the board exactly as when B C A was full, though the vessel contains just half the weight of water which previously occupied it.

474. Thus, you perceive that the form of the vessel has nothing to do with the degree of pressure produced by the fluid which it happens to contain; but this pressure is determined, at every point, by the perpendicular depth of that point below the level of the surface of the liquid. This is the inevitable consequence of the great law of fluid pressure, that it acts equally in all directions.

475. Thus, in the different vessels A, B, C, D, Fig. 183, if all filled with water to the same level, E F, the fluid pressure upon any one particle at the bottom of one vessel, —D, for example,—must be exactly equal to that exerted upon every other particle at the bottom of either of the vessels;—B, for example—because those particles are all at the same perpendicular depth beneath the common surface, E F; and, by the equality of action and reaction, the upward pressure against each particle of the fluid at the bottom of all these vessels, must also be equal. But suppose that either of the vessels contained water to a less depth than the others, then each particle at the bottom of this vessel must sustain proportionally less pressure. If, then, these vessels, A, B, C, and D, be connected by a tube communicating freely from one to another throughout the series,—which

Fig. 183.

tube you may suppose to be concealed in the base of the apparatus, as at G H, Fig. 184—on pouring more water into either vessel, you increase the downward pressure upon every particle at the bottom of that vessel; and as this pressure acts equally in all directions, it produces an equal increase of the upward pressure of the water contained in the concealed tube, throughout its entire length; which latter reacts upon all the particles contained in the other vessels, giving them all an increased disposition to rise towards the surface. But the upward pressure of each particle was already sufficient to balance its weight or downward pressure, before more water was added. Now, therefore, the former must overbalance the latter; and hence the water added must distribute itself to all the other vessels until it rises to the same level throughout the series; nor can the surface of any fluid be preserved at rest in the absence of disturbing forces, unless all parts of the surface stand at the same elevation.

476. As the pressure of any given liquid depends entirely upon its perpendicular depth, and not upon the form of the vessel containing it, it follows that, in all vessels containing any one liquid, and having bottoms of equal size, the whole pressure supported by the bottoms must be equal, if the depth be equal. But if the bottoms vary in size, the pressure sustained by them will be proportional to the dimensions of the bottom in each case.

477. At A, B, C, and D, Fig. 184, you see the representation of a number of vessels containing water to the same depth in each. The bottoms of all these vessels are of the same dimensions; that is, they all present surfaces containing the same number of square inches. On every square *inch in the* bottom of each of these vessels, the pressure is

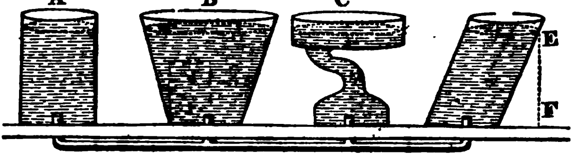

Fig. 184.

equal to the weight of a column of the liquid of the same dimensions, and of the height represented by the dotted line E F, which is equal to the depth of liquid in each of the vessels. Hence the dimensions of the bottom in square inches, multiplied by the perpendicular depth of the fluid in linear inches, multiplied again by the weight of a cubic inch of the fluid, will give the amount of pressure on the bottom in all cases, if the bottom be parallel to the surface.

478. The bottom of Lake Erie is said to be about 300 feet in depth. If this be true, and a hole with a surface of one square inch were bored in its deepest point, and connected with a pipe leading to the sea, the water could be effectually prevented from running out by a plug exerting about one-seventh of the force required to stop an iron tube full of water, one inch in diameter, and descending from the Catts-kill Mountain-house, at the Pine-orchard, to the village at the base of the mountain. The Mountain-house is elevated 2,000 feet above the village; and a cubic inch of water, when the thermometer stands at 62° Fahrenheit, weighs exactly 252.458 grains. From these data you would find that the water in the lake would endeavour to escape with a force equal to nearly 130 pounds avoirdupois, while the force sustained by the plug in the iron pipe would be more than 867 pounds. A strong man might hold in the waters of the lake with his hand, but the iron itself must be made very thick in order to resist the enormous pressure upon the tube.

479. As the pressure of liquids increases in direct proportion to the depth, without regard to the form of the vessel, it follows that the pressure upon the sides of a vessel must be measured by its extent of surface and the mean depth of the fluid pressing upon it. Thus, in Fig. 185, if the vessel be filled with water, the pressure on the portion of inner surface C D E, will be equal to the area of that portion multiplied by the depth H I; because, H is the middle point of the parallelogram acted upon by the water, and the whole pressure above that point must diminish as the surface of the

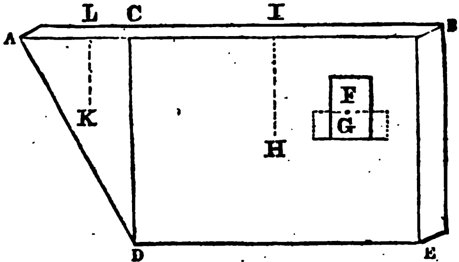

Fig. 185.

side of the vessel approaches the surface of the water, where it ceases altogether; while, on the other hand, the pressure below the point H, increases with exactly the same rapidity until the side reaches the bottom: H I, then, represents the depth of the point where the degree of pressure is equal to the average of that exerted upon the whole surface of C D E, and this is equally true, whether the side be perpendicular or oblique.

480. But if the side of a vessel be triangular, like the surface A C D, the mean depth of the liquid pressing upon it must be much less than H I; for the mean height of a triangle is always exactly one-third of its entire height measured from either of its sides. The whole pressure upon A C D is, therefore, equal to its area multiplied by the distance from the surface of the water to the point K, which is the mean depth of the liquid acting upon that surface.

481. The black dot at F, marks the mean depth of the fluid acting upon the small parallelogram of which it is the centre, and the distance from this point to the surface of the water multiplied by the area of the parallelogram will show the amount of pressure acting upon a flood-gate of the size, form and situation represented by the parallelogram. Now, suppose that this flood-gate, retaining the same dimensions and extending to the same depth, were placed in the horizontal position represented by the dotted lines round the letter G, which defines the mean depth of the water pressing on the gate when in that position. The depth from the surface of the water to G is much greater than that from the same surface to F; and, therefore, the pressure on the horizontal gate must be much greater than that acting on the perpendicular gate. This fact is of much importance in the construction of mills; for you perceive that a flood-gate three feet high, and one foot wide, placed at the bottom of a mill-race, would deliver much less water, and be much less

fective, than a gate one foot high and three feet wide, placed in the same situation. As fluid pressure is *immediately* applied to all surfaces by the layer of fluid particles in immediate contact with the surface, which layer may be considered indefinitely thin and of uniform density and thickness, the point of mean pressure may be easily ascertained in all cases, by finding where would be placed the centre of gravity of this layer.

482. The principles that have now been explained will enable you thoroughly to comprehend a great variety of interesting phenomena, that appear exceedingly puzzling to the uninstructed; we will mention a number of these, and your own observations will supply you daily with more.

483. The Atlantic Ocean rises in the Bay of Mexico to the height of many feet above the level of the Pacific on the western coast of the Isthmus of Panama. When it was first proposed to dig a canal through the isthmus, in order to facilitate our trade with India, many men, who should have been wiser, protested against the scheme for fear the vast ocean on the east should rush through the opening with resistless force, tear away the foundations of the Andes, and leave our shallower harbours almost dry. You have seen that it is as easy to shut out an ocean by a flood-gate as to secure an ordinary mill-dam by such means, if both gates be placed at the same depth.

484. When a bottle filled with fresh water, and tightly corked, is sunken to a great depth into the sea, the cork is compressed into a very small space by the weight of the liquid pressing it on every side, and is generally forced into the bottle in consequence of the compression of the water itself. If the cork retains its place, the sea water passes by the side of it, and the bottle is drawn upward, filled by a mixture of fresh and salt water.

485. When quantities of meat are placed in a sack full of brine and sunken in the same manner, for a very short time, the meat is drawn up completely salted, although it requires months to accomplish the same purpose without pressure.

486. Suspend a bucket, completely full of water, from one extremity of a long stick, and balance it across the sharp edge of a fence-rail, by hanging a stone of sufficient weight at the other extremity. Then plunge your hand into the bucket and hold it there, without touching the bottom or sides of the vessel, and you will find the equilibrium still unchanged; because the height of the fluid remains unaltered: but, if the same experiment be repeated with the bucket only partially filled with water, it will immediately prepon-

derate; because the depth of the water is increased. This is called the hydrostatic paradox, and is clearly illustrated in the little apparatus represented in Fig. 186. A represents a vessel suspended like a scale from one extremity of a common weighing beam; B, a cylindrical piece of wood or metal, large enough nearly to fill the former, and supported by a rod, C, which slides upon the pillar of the beam, upon which it can be secured at any height, by means of a thumb-screw. Let A be completely filled with water, and weighed while B is removed from the vessel; then cause B to descend into the vessel, so as to displace any required portion of the water, and secure it in its new position by means of the screw. In this case, A will be found to balance just as much weight as before, though much water has flowed from it; because the depth of the liquid pressing upon the bottom continues unchanged. This result takes place with equal certainty, whether B be made of lead or cork. If a water-tight case, basin or dock were made sufficiently large to receive a ship of 1,000 tons burden, fully loaded, and if the shape of the dock were so adapted to that of the bottom of the vessel as to leave very little room between them, the ship would float as completely, when borne up by a few gallons of water poured into the dock as when sailing on the ocean.

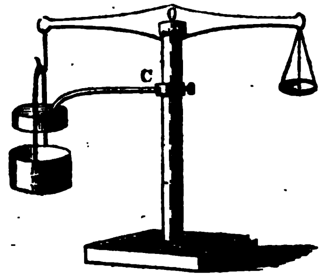

Fig. 186.

487. If a long tube, with a section of one square inch, were made to enter an iron-bound and water-tight hogshead, filled with water, and if more water were then poured into the tube, the pressure on every square inch over the whole internal surface of the hogshead would be increased at the rate of 252.458 grains, or about 11-20ths of an ounce, troy, for every inch of distance to which the water would rise in the tube; and as there are nearly 4,000 square inches on the inner surface of a hogshead, every square inch of water in the tube would press upon this surface with a force of

Fig. 187.

about 144 pounds. It is not surprising, then, that a column of a few feet in such a tube is sufficient to burst the strongest hogshead.

488. Suppose that we substitute for a long column of water in the tube, A, Fig. 187, the piston represented at B, carrying upon the summit of its rod, a small scale, C, in which we place a weight of one pound, the tube being filled with water as far as the piston. In this case, the piston will press upon the water in the tube with a force equal to that of a column of the liquid weighing one pound; which column would be more than twenty-seven inches in height. The outward pressure on the inside of the hogshead, from the action of the weight alone, would then be equal to one pound on every square inch of surface, or nearly 4,000 pounds. And if the tube were made of only one quarter the dimensions, the same pound of weight would exercise a pressure of one pound on every one quarter of a square inch; thus reaching the enormous amount of 16,000 pounds, which no such vessel could sustain for an instant.

489. The foregoing remarks are sufficient to prove one of the most curious consequences of the law that liquids act equally in all directions. It is this: *When a portion of a fluid is subjected to any force whatever, that force acts with equal energy throughout the entire mass of the fluid.* Thus, if you tread upon a bladder filled with water, it will give way wherever it is weakest, and not necessarily at the part where you place your foot; for your weight acts just as powerfully on all other portions of the inside of the bladder. Indeed, by flattening the sides of the sac, and supporting it by pressure without as well as within, the foot and the ground against which it is pressed, actually strengthen these portions of the membrane by enabling their cohesion to act at a greater mechanical advantage in resisting the distension. Here we meet an apparent paradox: the part least likely to burst is the very part to which the force is directly applied.

490. By means of a tube and piston, similar to that seen in Fig. 187, but generally worked by a lever, like a pump, the strength of steam-boilers, cannon and other hollow vessels are most conveniently tested. By choosing a small tube, and using a strong lever to act upon the piston-rod, it is easy for a single man to produce a pressure of millions of pounds upon the interior of these vessels, when filled with water. There is no cannon so strong that it may not be torn to pieces by a mere child, when armed with such tremendous mechanical power.

491. One of the most useful applications of liquid pressure to mechanical purposes is seen in the Bramah press, represented in section at Fig. 188. Its explanation and elucida-

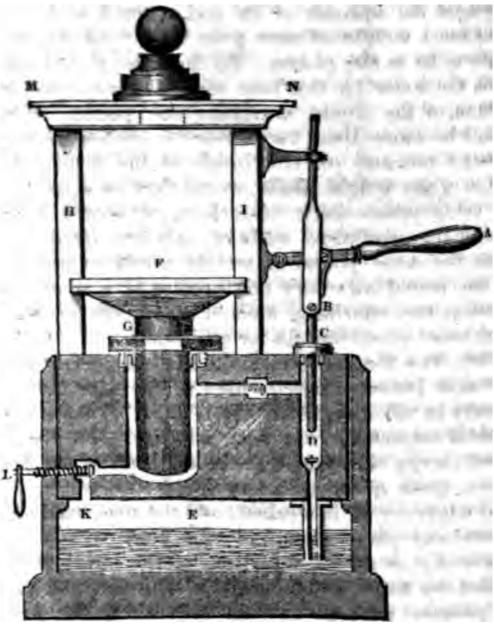

Fig. 188.

tion will demand your closest attention for a few moments. All the darkly shaded parts of the machine, the upright posts or pillars H and I, with the cross-piece uniting them at the top, are composed of massive iron. A is the handle of a lever of the second order, attached, by a joint which serves as its fulcrum, to the pillar I. It acts on a small piston-rod, B C, by means of a short lever and hinge-joint. At C, the piston-rod descends through a strong iron air-tight cap, into a narrow chamber, D, in the solid iron, which serves as part of the barrel of a pump; but the piston-rod carries no piston at its extremity, and its transverse section measures one-fourth of a square inch. The chamber or pump-tree is connected with the water in the large chamber

or pump-well E, by means of an iron tube. Near D, in the pump-tree, you perceive a little valve, which rises and permits water to flow upward through it, when drawn by the pump in that direction, but shuts down again the moment it attempts to return. Considerably above D, you see an open canal cut through the solid iron, and passing to the left. This canal communicates with a large cylindrical chamber, represented as almost completely filled by a cylinder of solid iron, which descends into it from above, through an air-tight iron cap at G. This cylinder is in fact an enormous piston-rod, working in the great chamber. It carries on its summit a very strong and massive iron table, F, provided with grooves on its edge, which partially embrace the pillars H, I, and permit the table to slide freely up and down, when the great cylinder G is put in motion. In the middle of the little horizontal canal leading from the pump-tree D to the cylindrical chamber, you perceive another small valve, having a slender helix-spring, which extends towards the chamber, and keeps the valve habitually closed by its elasticity. If water be forced from the pump-tree into the horizontal canal, its pressure will compress the helix-spring and push this valve open, so as to allow the water to flow towards the cylindrical chamber; but the moment this water attempts to return towards the pump, the spring drives the valve into its place again, and closes the canal. At the bottom of the cylindrical chamber, another little canal is seen passing horizontally to the left for a short distance, then turning downwards at a right angle, and entering the pump-well at K. When this canal is open, any water thrown into the cylindrical chamber will run back into the pump-well; but at L you see a screw passing through the side of the machine, and formed into a smooth plug at its inner extremity; so that when this screw is tightened, the little canal is closed at its angle, and thus water is prevented at pleasure from escaping in this direction.

492. We will now consider the action of the Bramah press when first put in motion. The two first valves being closed, one by its weight, the other by its spring, while the screw-valve at L remains open, the pump-handle A is raised, and by this means the greater part of piston-rod C is drawn out of the pump-tree chamber D. The pressure of the piston-rod on the air in the chamber being thus diminished, the water rises from the pump-well into the chamber D, to supply the place of the rod (for reasons which will be explained when we speak of pneumatics), raising the valve by press-

ing upon it from below. The pump-handle is then depressed, and of course the valve at D is instantly closed, so as to prevent the return of the water. There is then more matter in the chamber D than there was at first, and as this gives less room for the piston-rod, its pressure must be increased, and a portion of the air will be squeezed or driven out through the valve in the horizontal canal, which readily opens to give it passage, but closes again to prevent its return. When the pump-handle is again raised, more water is drawn into the chamber D, and by repeating this process two or three times, nearly all the air is expelled, and D becomes nearly full of water. As the pump continues to work, a quantity of water equal to the size of the piston-rod enters the pump-tree at every ascending stroke, and the same quantity is forced through the horizontal canal into the great cylindrical chamber, at every descending stroke of the handle A. The cylindrical chamber being thus freely supplied with water, the screw K is tightened, and all escape from the cylinder is thus prevented.

493. The machine is now ready for use. Any thing that we wish to subject to pressure is laid upon the iron table F, and over it are placed planks, masses of iron, or wedges of any other character that possess sufficient strength, until all the space between the cross-piece M N and the body to be pressed is occupied by unyielding solid materials. The pump is then again set in motion, and as the cylindrical chamber becomes gradually filled with water, the great iron cylinder G is forced upward, making pressure upon the substance upon which we wish to operate through the medium of the table F. When the resistance of the compressed substance has become so great that the table F can rise no farther, the pump is stopped; but still the pressure is maintained; because the little spring-valve in the horizontal canal acts just as powerfully upon the water in the cylindrical chamber as the piston-rod of the pump had previously done. Thus the force may be continued until the screw L is relaxed.

494. We will now make a little calculation of the force of the Bramah press. Let the length of the pump-handle A be four feet, and the distance from the joint or fulcrum to the piston-rod six inches. By the law of the lever, this multiplies the power eight times. If the entire weight of two men, each weighing one hundred and fifty pounds, be thrown into action upon this lever, the force acting upon the piston-rod, neglecting the loss by friction, would be at least $300 \times 8 = 2400$ pounds. Now, the horizontal section of the

piston-rod in this case does not exceed one-quarter of a square inch; and upon this small surface the whole force of the lever takes effect. But forces applied to bodies of liquid are diffused equally through all parts of those bodies, and act equally in all directions. Therefore, the pressure on the surface of the chamber D with its valve, the horizontal canals with their valve and plug, the cylindrical chamber, and the great iron cylinder, is equal to 2400 pounds on each fourth part of a square inch, or 9600 pounds on each square inch. The portion of this pressure which tends to elevate the table F, is that which acts perpendicularly upward against the lower extremity of the cylinder G; and if the transverse section of this cylinder measure 64 square inches, the whole pressure exerted on the table F must amount to $9600 \times 64 = 614{,}400$ pounds, or 274 tons 5 cwt. 2 qr. 24 lb.

495. It is not difficult, with this machine, to bury a quire of paper into a wooden plank, and water has been forced by it through the pores of gold. It is said that the water from the cylindrical chamber sometimes appears in drops on the outside of its thick iron walls; as if the machine were actually perspiring with its excessive exertions.

496. Though liquids have naturally level surfaces when undisturbed, because their particles press equally in all directions, the surfaces of great lakes and seas are never absolutely level, because they are always disturbed, wholly or in part, by winds and other forces, which drive and pile up the water before them; but the liquid perpetually seeks to return to a state of rest by stealing off in any direction where the disturbing force does not act, or acts but feebly. This is the origin of currents, which perpetually tend to bring the fluid to its true level. The surface of the Gulf of Mexico is invariably higher than the surface of the North Atlantic, or the water on the opposite shores of Africa, because certain constant forces connected with the revolution of the earth, which we are not yet fully prepared to explain, keep the water piled up against the western shores of the ocean, within the tropics; but between the island of Cuba and the coast of Florida, these forces do not act to the same advantage; and here the water steals out of the gulf in a gigantic and rapid stream, sweeping northward along the coast of the United States. Blow with your breath across a large tumbler nearly full of water, and you will see a beautiful illustration of the nature and source of the causes of currents; for the whole surface will be converted into two equal and opposite whirlpools by the joint action of the wind and the shores of this mimic lake.

497. The equality of the pressure of liquids in all directions is productive of many other phenomena of great importance, and capable of being foretold by an acute reasoner, without the aid of experiment, when the laws of fluid pressure are well understood; but their dependence thereon is not so obvious to a mere tyro in the study of physics, and it is therefore necessary to give them special illustration.

498. Let A be a glass vessel nearly filled with water or any other liquid; B, an open glass tube of moderate dimensions; C, the surface of the liquid; and D, a piece of metal, polished so as to cover the lower orifice of the tube and keep out the liquid, when applied. Let the weight of D be fixed;—say one ounce. Now, if B be held perpendicularly in the air, and D be applied as in the figure, the latter will fall off; for there is no force in action to resist its gravitation. If D be held in its place until the tube is lowered so that the metal may just touch the water, it will fall and sink by its weight, because the water cannot press upward against an object exactly on its own level. Let the tube and metallic plate be carried down a short distance below the surface, and then let D be left free. Still it will sink, because it still overbalances the upward pressure of the liquid in the basin. Now, let the tube and metallic plate be carried deeper into the basin, until the solid content of that part of the tube which is below the general surface of the liquid would hold, if filled from the basin, a weight of liquid exactly equal to that of the metallic plate, when the latter is above the surface. You will at once perceive that if D were now removed, the pressure of the liquid on the outside would force up a portion of liquid into the tube, which would fill it to the general level; that is, the upward pressure at D would support a weight of fluid exactly equal to that of D; or, in other words, *it would support the weight of D;* which, therefore, could not sink. Under such circumstances, the metal may be said to have lost all its weight, when the word weight is used in its vulgar sense. It *floats* against the end of the tube more lightly than a cork on the surface; yet a few drops of water quietly placed on its upper surface, within the tube, would instantly cause it to sink, by increasing its weight. If the tube were now driven still deeper into the liquid, the upward pressure would continually increase; the

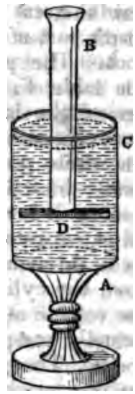

Fig. 189.

ate D would press more and more firmly against the glass; and if the latter were long and strong enough to reach to a sufficient depth in the ocean, we might pour into the tube a hundred pounds of quicksilver, or *mercury*, without driving off and opening the tube. If we neglect the effect of the pressure of fluids in increasing their own density as they grow deeper, this experiment is explained at once by the law that the pressure of fluids increases directly as their depth. But we must here give you some other examples.

499. Let A, Fig. 190, represent a light body floating on the surface of water. Whatever the weight of this body may be, it is evident that the upward pressure of the water must support it; for otherwise it would sink: *And this upward pressure must be exactly equal to the weight of the body;* for if it were less, the body would not be fully supported, but would subside more deeply into the water; and if it were greater than the weight, it would push the body up higher, instead of balancing it. That part of the floating body which sinks below the water must obviously displace exactly its own bulk of the liquid; and it is obvious that before the body touched the water, this same bulk of water was supported and kept at rest by the upward pressure of the liquid around it, just as the floating body itself is supported and kept at rest. The water, therefore, which has been displaced by the body, and which was previously exactly balanced by the upward pressure of the water around it, must weigh exactly as much as the floating body itself when weighed in the air. Therefore; *A body floating upon a liquid must displace a quantity of that liquid exactly equal to itself in weight, and is buoyed up by an upward pressure exactly equal to the weight of this displaced liquid.*

Fig. 190.

500. If we now suppose the body A to be rendered heavier by the continued addition of small pieces of lead or some other substance more dense than water, until it sinks so as to float with its uppermost point just in contact with the surface, it will displace a quantity of water equal to its whole bulk, *and will be buoyed up by a force equal to the weight of that bulk.* It may therefore be said to weigh *nothing* in water, and will neither tend to sink nor to rise. If both the liquid and the solid body were absolutely incompressible, this exact balance between them would be

preserved at all depths in the liquid, for everywhere it will displace precisely its own bulk of water, which water will be exactly balanced by the surrounding liquid pressure, if the body were not there; and this pressure would act on the body exactly, and in all respects, as it acts upon the same bulk of water before displacement. Now the upward pressure of the liquid, having nothing to do with the nature of the immersed body, but being dependent merely upon its bulk or the quantity of water which it displaces, it will not be influenced by the density of the body, but will remain the same under the same circumstances, whether the body be composed of cork or lead. Let us, then, suppose that A, Fig. 190, is a piece of cork, which weighs about one-quarter as much as the same bulk of water; and let its weight be one ounce. If this body be thrust beneath the surface, it is evident that it must displace four times its weight of the liquid; consequently, the liquid will buoy it up with a force equal to four ounces; but, as it gravitates towards the earth as strongly in the water as in the air, it still strives to sink by its own weight with a force of one ounce. The buoyant force overcomes that of gravity, and if the cork be left free, it will rise with a force equal to the difference between these two contending forces; that is, with a force of three ounces. If we may be allowed the expression, it has lost four times its own weight by being immersed in water; for it has lost not only all its own *one ounce* of weight when placed in a balance, but it requires a weight of three ounces more to make its weight *nothing* in the water. Thus you see that *when a body capable of floating in any liquid is wholly immersed in that liquid, it loses a portion of its weight equal to that of its own bulk of that liquid.*

501. It is evident, then, that when a body of the same relative weight with any liquid, is immersed therein, it loses a weight equal to that of its own bulk of the liquid, because it displaces just that bulk, and loses just the whole of its own weight.

502. Let us now suppose the body A, Fig. 190, to be composed of *topaz;* a gem that is about four times heavier than water. The body would then sink in water, displacing, as it entered, its own bulk of the liquid; but it would be subject to the same amount of upward pressure as if it were either lighter or heavier; for it is the gravitation of the fluid, and not that of the body, that determines this pressure. Now, the topaz, having the same form as the cork in the former experiment, will displace the same quantity of water, and

will therefore be subjected to the same amount of upward pressure when immersed: and that amount has been shown to be four ounces (499). The topaz would, therefore, weigh four ounces less in the water than it does in the air. But, as has been stated, it is relatively four times heavier than water, and must, therefore, weigh 16 ounces in the air, and 12 ounces in the water;—the difference of these weights being the amount of the upward pressure of the liquid, which is equal to the weight of the displaced water. Hence you perceive that the law laid down at the end of the 499th paragraph may be extended to all bodies, whether relatively heavier or lighter than the liquid. Let us give it this general expression: *Any body immersed in any liquid loses a portion of its weight equal to the weight of a similar bulk of that liquid.*

503. This rule would be equally applicable, even were liquids obviously compressible by their own weight, so as to be more dense or relatively heavy at the bottom of the immersed body than they are at its upper surface; for the body would still displace its own bulk of the liquid, which weight, previously to the presence of the body, had been exactly balanced by the upward pressure of the surrounding liquid, and this upward pressure would therefore take effect to the same extent upon the body itself. Now, you know that the only dynamic difference between airs or gases—*aeriform fluids*, as they are called—consists in the greater expansibility and consequent compressibility of the latter, which causes them to increase in density much more rapidly than the former, in proportion to their depth. Therefore, the law just laid down may be extended to aeriform fluids as well as liquids; and we beg you carefully to commit this law to memory, as soon as you thoroughly understand it, in its following most simple and general form.

504. A body immersed in any *fluid* loses a portion of its weight equal to the weight of a similar bulk of that *fluid*.

505. As the difference between the weight of a body when surrounded by *nothing*, or placed in empty space, and its weight when immersed in a fluid, measures the weight of an equal bulk of the fluid, it follows that, in order to discover the relative weight of any body, compared with that of any fluid, it is only necessary to ascertain the absolute weight of the body, and then, weighing it again in the fluid, divide the absolute weight by the difference of these weights. The result will be the relative weight of the body when compared with the fluid; for it will show how many times the

20

weight of the latter is contained in that of the former. Thus, suppose the cork A, Fig. 190, to weigh one ounce when surrounded by empty space, which physical philosophers call *vacuum;* suppose it also to require this ounce and an additional weight of three ounces to immerse it in water. The difference between these weights, which is the weight of a bulk of water equal to the size of the cork, is four ounces. Divide the former weight by the latter, and the dividend, one-quarter, will express the relative weights of cork and water. Again: a topaz weighing twelve ounces in water is found to weigh about sixteen ounces in a vacuum. The difference—four ounces—represents the weight of an equal bulk of water. Divide the weight *in vacuo* by this difference, and we have the number 4 to represent the relative weight of topaz, when compared with that of water, under all circumstances.

506. You perceive that, in these experiments, we compare the weights of equal bulks of different substances with each other, and obtain numbers which express the proportions which these weights bear to each other. This gives us a most valuable power of arithmetical calculation; for instance, if we assume water as a standard or unit, the weight of a cubic inch or cubic foot or any other given quantity of water being called 1, the weight of a corresponding quantity of topaz will weigh four times that amount, and a like quantity of cork will weigh one-quarter that amount. Now, if we form a scale of such relative weights, by comparing all substances with water or any other fluid standard, and if we know, by actual experiment, the absolute weight of any given quantity of the standard, we can ascertain, by mere multiplication and division, the weight of any quantity of any other substance, provided we know its bulk or size. Such scales have been formed, and it has been found most convenient to adopt the 0.001 part of a cubic foot of pure water, at the temperature of 40 degrees of Fahrenheit, as the unit or standard for solids and liquids, because a cubic foot of that liquid, at that temperature, and in the ordinary condition of the atmosphere, weighs almost precisely 1000 ounces avoirdupois; and its 0.001 part, therefore, weighs 1 ounce. In the appendix, you find a list of the relative weights of a multitude of substances calculated upon this scale. Aeriform fluids may be reduced to the same scale, and some of these appear in the table, but the gases are so extremely light when compared with water, that it is more usual to compare them with atmospheric air, taking the

weight of air at an average temperature and condition of the atmosphere, as the unit of the scale.

507. As we have continual occasion to speak of the relative weights of bodies, we feel the want of a short term to express this idea:—*the relation in quantity between the weight of any bulk of matter of any kind, when compared with that of an equal bulk of some other kind of matter, chosen as a standard, the relative weight of the latter being considered as the unit of the scale of comparison: The term chosen to express this idea* is SPECIFIC GRAVITY. Endeavour to understand this explanation clearly, and then you may be contented with remembering the following *practical* definitions.

508. The *specific gravity* of a body is the number expressing its relative weight when compared with the weight of an equal bulk of some other substance chosen as a standard.

509. The common standard of specific gravity for solids and liquids, is water at its point of greatest density.

510. Specific gravity is a measure of density; for density depends on the quantity of matter contained in a given space, and so does relative weight. Therefore, specific gravity, explained in the shortest possible phrase, is—*the relation of weight.*

511. The denser of any two fluids—that is, the one having the greatest specific gravity—if the two cannot combine with each other, will always endeavour to settle down and assume the lower position, thus obliging the lighter to rise above it; and the cohesion of solids alone prevents them from displaying the same tendency, by rendering their particles relatively immoveable by the force of gravity. But mix together equal quantities of sand, wheat, and chaff; place them upon a deep dish, and agitate the dish for some time, by drumming smartly with the hand on its under surface, and you will then find most of the sand at the bottom of the dish, most of the wheat on the surface of the sand, and most of the chaff on the surface of the wheat, in the order of their specific gravities. Mix, in a bottle, a quantity of mercury, iron filings, muddy water, fine sand, sawdust from box-wood or *lignum vitæ*, and small pieces of cork. Having shaken them till thoroughly wet, add olive oil; shake the bottle again violently until all are completely mixed, and let it stand at rest for an hour. All these substances will then be found arranged in strata according to the order of their specific gravities; namely, 1, mercury, at the bottom; 2, iron floating on the mercury; 3, sand; 4, mud; 5, water; 6, box-wood or lignum vitæ; 7, oil; 8, cork. You may

now pour a little alcohol on the surface of the oil. It will remain there, but the cork will rise through it and take the upper place. By great care and skill, you might place above these a stratum of carbonic acid gas, another of atmospheric air, and a third of hydrogen gas,—which would remain separate for a time. Here, then, you have the same principle displayed in twelve different strata, some solid, some liquid, and some gaseous.

512. The word *medium* is used to express the space or substance by which a body is immediately surrounded: thus, vacuum is a medium offering no resistance to light; air is the medium in which we move; water is the medium in which fishes reside. To ascertain the specific gravity of a body, we commonly weigh it first in one of these two last-named *media*, and then in the other.

513. You perceive that when a body is placed in a medium of less than its own density or specific gravity, it sinks—if of greater, it rises. But bodies that are compressible (and what bodies are not?) may have their density increased by the application of force or diminished by the removal of forces already acting upon them. Take a bottle-cork, pass a string through it, and suspend thereto a very small scale or pan of sheet-metal, taking care that the specific gravity of the scale and cork together shall be less than that of water. Place this apparatus in a deep vessel of water, and it will float. Load the scale gradually with sand until it sinks the top of the cork nearly to the level of the liquid. The specific gravity of the whole apparatus is then about equal to that of water. Now, tie a string tightly round the cork. This will compress it, render it more dense, or increase its specific gravity, and it will sink. Then cut the string, and the cork will again expand, become rarer or less dense, diminish in specific gravity, and it will rise.

514. Aerial fluids are very compressible. Let Fig. 191 represent a long glass vessel containing water, and covered with bladder, so as to be air-tight. Let A be a small glass flask with its mouth inverted, containing air enough to render it specifically somewhat lighter than water, even when the little image seen in the figure is suspended to it; and let there be a free communication between the cavity of the flask and the water, through the neck. If now you press firmly on the bladder with your finger, the air above the water in the vessel will be compressed and will react upon the water, the upward pressure of which, through the neck of the *flask, will be* increased. This upward pressure will react

compressible air within the flask, g it denser, increasing the specific of the whole apparatus until it be- greater than that of water, and it k. Take off your finger, and the air ask will expand, and again cause this *alloon* to rise. When very nicely , this toy may be made to float when at the surface, yet may be incapable g when thrust to the bottom.

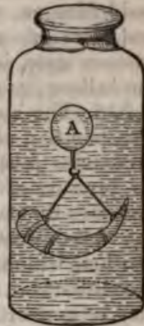

Fig. 191.

A common balloon is a great bag of rounded by a net of cord, carrying pable of holding one or more men. is gradually filled with hydrogen gas, h the specific gravity is only 1-13th great as air, until the specific gravity whole apparatus, together with the traveller or *aero-* d his baggage, becomes less than that of air. The

Fig. 192.

balloons is usually obtained by pouring diluted sulphu- l upon filings of iron in barrels, which causes a de-

ing upon it from below. The pump-handle is then depressed, and of course the valve at D is instantly closed, so as to prevent the return of the water. There is then more matter in the chamber D than there was at first, and as this gives less room for the piston-rod, its pressure must be increased, and a portion of the air will be squeezed or driven out through the valve in the horizontal canal, which readily opens to give it passage, but closes again to prevent its return. When the pump-handle is again raised, more water is drawn into the chamber D, and by repeating this process two or three times, nearly all the air is expelled, and D becomes nearly full of water. As the pump continues to work, a quantity of water equal to the size of the piston-rod enters the pump-tree at every ascending stroke, and the same quantity is forced through the horizontal canal into the great cylindrical chamber, at every descending stroke of the handle A. The cylindrical chamber being thus freely supplied with water, the screw K is tightened, and all escape from the cylinder is thus prevented.

493. The machine is now ready for use. Any thing that we wish to subject to pressure is laid upon the iron table F, and over it are placed planks, masses of iron, or wedges of any other character that possess sufficient strength, until all the space between the cross-piece M N and the body to be pressed is occupied by unyielding solid materials. The pump is then again set in motion, and as the cylindrical chamber becomes gradually filled with water, the great iron cylinder G is forced upward, making pressure upon the substance upon which we wish to operate through the medium of the table F. When the resistance of the compressed substance has become so great that the table F can rise no farther, the pump is stopped; but still the pressure is maintained; because the little spring-valve in the horizontal canal acts just as powerfully upon the water in the cylindrical chamber as the piston-rod of the pump had previously done. Thus the force may be continued until the screw L is relaxed.

494. We will now make a little calculation of the force of the Bramah press. Let the length of the pump-handle A be four feet, and the distance from the joint or fulcrum to the piston-rod six inches. By the law of the lever, this multiplies the power eight times. If the entire weight of two men, each weighing one hundred and fifty pounds, be thrown into action upon this lever, the force acting upon the piston-rod, neglecting the loss by friction, would be at least $300 \times 8 = 2400$ pounds. Now, the horizontal section of the

C. If, then, we pour water into C, until the mercury is driven down to the curve of the tube at E, the water will stand 13.6 times as high above the bend in one branch as the mercury will in the other branch. That is: *the heights of incompressible liquids in tubes communicating* with each other, measured from their surfaces *of contact, are inversely proportional to their relative densities or specific gravities.* Let both arms of such a bent tube be marked with corresponding scales of equal parts, divided into inches and parts of an inch. Then, upon filling the tube with mercury to a certain height, and afterwards pouring into either arm any liquid which does not act chemically upon mercury, you have the means of determining, by simple inspection, the relative heights of the columns of the two liquids above the surface of contact between them; and, these lengths being inversely proportional to their relative densities, if we divide the length of the liquid which we are testing, into that of the column of mercury above the surface of contact, the result will be the specific gravity of this liquid when compared with mercury as a standard. If this result be multiplied by 13.6, which is the specific gravity of mercury when compared with water, the result will be the specific gravity of the tested fluid, also compared with water. Such an instrument will answer many purposes in the arts.

519. There are many machines employed for the purpose of ascertaining specific gravities. Those of solid bodies heavier than water are usually obtained by means of a delicate weighing-beam and two well-balanced scales—Fig. 194, beneath one of which there is a small metallic hook. In this scale, the body is first weighed in air, and its weight noted. It is then suspended from the hook by a hair or thread, and is again weighed in water. The difference between these weights being divided into the former weight, gives the specific gravity of the body.

Fig. 194.

520. A very ingenious instrument for obtaining specific gravities was invented, many years ago, by Benjamin Hornor Coates, M. D., of Philadelphia, and is described in the Journal of the Academy of Natural Sciences of Philadelphia.

tube until it reaches the bend, B, flows over, and fills the long arm. The finger is then removed. There are now two columns of water in the two arms of the syphon, both tending to fall by their gravity. The liquid between A and the level of the surface at E, is exactly balanced by the hydrostatic pressure of the liquid in the vessel; but the column from E to B endeavours to fall back into the reservoir, while that from B to C endeavours to fall out at the orifice, C. The pressure of the atmosphere prevents the two columns from parting at B, which would create a vacuum; and, consequently, the longer column overbalancing the shorter, the latter is compelled to follow the motion of the former,—while, for the same reason, the fluid rushes from the vessel into the tube at E, to supply its place. Thus, a current proportional to the difference between the perpendicular height of B E, and B C, is completely established, and the vessel is emptied.

570. Intermitting springs and wells are best explained upon the principle of the syphon. Let Fig. 211 represent the section of part of a mountain, containing a cave or basin within it, capable of holding water. Also, let numerous crevices in the rock or soil above, convey the water of rains or springs into this cavity, and let there be an outlet in the form of a syphon, formed by the rocky strata, descending, as is represented in the figure, to A.

Fig. 211.

The water, draining from the soil of such a mountain side, and descending into the cavity, will be detained there as in a basin; nor can it find an outlet until the syphon-like passage is filled with water up to its superior bend. It will then flow over and fill the remainder of the passage, down to A, and there the hydrostatic pressure of the column will force the water upward through the soil, to form a spring. But, as this passage plays the part of a true syphon, the spring will not cease to flow until all the water in the cavity is drained away. Then the flow must cease; nor can it be renewed until the cavity becomes filled again by fresh collections of water from above. Such a spring may flow very frequently during the spring and fall, and seldom, if at all, in the middle of summer. The phenomena of ebbing and flowing wells, and the irruptions of steam and boiling water, such as occur regularly in the hot springs of Iceland, may be explained on this principle, and may be imitated by art.

plate D would press more and more firmly against the glass; and if the latter were long and strong enough to reach to a sufficient depth in the ocean, we might pour into the tube a hundred pounds of quicksilver, or *mercury*, without driving it off and opening the tube. If we neglect the effect of the pressure of fluids in increasing their own density as they grow deeper, this experiment is explained at once by the law that the pressure of fluids increases directly as their depth. But we must here give you some other examples.

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505. As the difference between the weight of a body when surrounded by *nothing*, or placed in empty space, and its weight when immersed in a fluid, measures the weight of an equal bulk of the fluid, it follows that, in order to discover the relative weight of any body, compared with that of any fluid, it is only necessary to ascertain the absolute weight of the body, and then, weighing it again in the fluid, divide the absolute weight by the difference of these weights. The result will be the relative weight of the body when compared with the fluid; for it will show how many times the

weight of the latter is contained in that of the former. Thus, suppose the cork A, Fig. 190, to weigh one ounce when surrounded by empty space, which physical philosophers call *vacuum;* suppose it also to require this ounce and an additional weight of three ounces to immerse it in water. The difference between these weights, which is the weight of a bulk of water equal to the size of the cork, is four ounces. Divide the former weight by the latter, and the dividend, one-quarter, will express the relative weights of cork and water. Again: a topaz weighing twelve ounces in water is found to weigh about sixteen ounces in a vacuum. The difference—four ounces—represents the weight of an equal bulk of water. Divide the weight *in vacuo* by this difference, and we have the number 4 to represent the relative weight of topaz, when compared with that of water, under all circumstances.

506. You perceive that, in these experiments, we co[mpare] the weights of equal bulks of different substances wit[h each] other, and obtain numbers which express the prop[ortion] which these weights bear to each other. This giv[es us a] most valuable power of arithmetical calculation; [for in]stance, if we assume water as a standard or unit, the [weight] of a cubic inch or cubic foot or any other given qua[ntity of] water being called 1, the weight of a corresponding q[uantity] of topaz will weigh four times that amount, and a lik[e quan]tity of cork will weigh one-quarter that amount. [If] we form a scale of such relative weights, by compa[ring] substances with water or any other fluid standard, an[d] know, by actual experiment, the absolute weight [of a] given quantity of the standard, we can ascertain, b[y] multiplication and division, the weight of any qua[ntity of] any other substance, provided we know its bulk [.] Such scales have been formed, and it has been foun[d] convenient to adopt the 0.001 part of a cubic foot [of] water, at the temperature of 40 degrees of Fahren[heit, as] the unit or standard for solids and liquids, because [a cubic] foot of that liquid, at that temperature, and in the o[rdinary] condition of the atmosphere, weighs almost precisel[y 1000] ounces avoirdupois; and its 0.001 part, therefore, w[eighs an] ounce. In the appendix, you find a list of the [specific] weights of a multitude of substances calculated up[on this] scale. Aeriform fluids may be reduced to the same [scale,] and some of these appear in the table, but the gases [are so] extremely light when compared with water, that it [is] usual to compare them with atmospheric air, taki[ng]

weight of air at an average temperature and condition of the atmosphere, as the unit of the scale.

507. As we have continual occasion to speak of the relative weights of bodies, we feel the want of a short term to express this idea:—*the relation in quantity between the weight of any bulk of matter of any kind, when compared with that of an equal bulk of some other kind of matter, chosen as a standard, the relative weight of the latter being considered as the unit of the scale of comparison: The term chosen to express this idea* is SPECIFIC GRAVITY. Endeavour to understand this explanation clearly, and then you may be contented with remembering the following *practical* definitions.

508. The *specific gravity* of a body is the number expressing its relative weight when compared with the weight of an equal bulk of some other substance chosen as a standard.

509. The common standard of specific gravity for solids and liquids, is water at its point of greatest density.

510. Specific gravity is a measure of density; for density depends on the quantity of matter contained in a given space, and so does relative weight. Therefore, specific gravity, explained in the shortest possible phrase, is—*the relation of weight.*

511. The denser of any two fluids—that is, the one having the greatest specific gravity—if the two cannot combine with each other, will always endeavour to settle down and assume the lower position, thus obliging the lighter to rise above it; and the cohesion of solids alone prevents them from displaying the same tendency, by rendering their particles relatively immoveable by the force of gravity. But mix together equal quantities of sand, wheat, and chaff; place them upon a deep dish, and agitate the dish for some time, by drumming smartly with the hand on its under surface, and you will then find most of the sand at the bottom of the dish, most of the wheat on the surface of the sand, and most of the chaff on the surface of the wheat, in the order of their specific gravities. Mix, in a bottle, a quantity of mercury, iron filings, muddy water, fine sand, sawdust from box-wood or *lignum vitæ*, and small pieces of cork. Having shaken them till thoroughly wet, add olive oil; shake the bottle again violently until all are completely mixed, and let it stand at rest for an hour. All these substances will then be found arranged in strata according to the order of their specific gravities; namely, 1, mercury, at the bottom; 2, iron floating on the mercury; 3, sand; 4, mud; 5, water; 6, box-wood or lignum vitæ; 7, oil; 8, cork. You may

now pour a little alcohol on the surface of the oil. It will remain there, but the cork will rise through it and take the upper place. By great care and skill, you might place above these a stratum of carbonic acid gas, another of atmospheric air, and a third of hydrogen gas,—which would remain separate for a time. Here, then, you have the same principle displayed in twelve different strata, some solid, some liquid, and some gaseous.

512. The word *medium* is used to express the space or substance by which a body is immediately surrounded: thus, vacuum is a medium offering no resistance to light; air is the medium in which we move; water is the medium in which fishes reside. To ascertain the specific gravity of a body, we commonly weigh it first in one of these two last-named *media*, and then in the other.

513. You perceive that when a body is placed in a medium of less than its own density or specific gravity, it sinks—if of greater, it rises. But bodies that are compressible (and what bodies are not?) may have their density increased by the application of force or diminished by the removal of forces already acting upon them. Take a bottle-cork, pass a string through it, and suspend thereto a very small scale or pan of sheet-metal, taking care that the specific gravity of the scale and cork together shall be less than that of water. Place this apparatus in a deep vessel of water, and it will float. Load the scale gradually with sand until it sinks the top of the cork nearly to the level of the liquid. The specific gravity of the whole apparatus is then about equal to that of water. Now, tie a string tightly round the cork. This will compress it, render it more dense, or increase its specific gravity, and it will sink. Then cut the string, and the cork will again expand, become rarer or less dense, diminish in specific gravity, and it will rise.

514. Aerial fluids are very compressible. Let Fig. 191 represent a long glass vessel containing water, and covered with bladder, so as to be air-tight. Let A be a small glass flask with its mouth inverted, containing air enough to render it specifically somewhat lighter than water, even when the little image seen in the figure is suspended to it; and let there be a free communication between the cavity of the flask and the water, through the neck. If now you press firmly on the bladder with your finger, the air above the water in the vessel will be compressed and will react upon the water, the upward pressure of which, through the neck of the flask, will be increased. This upward pressure will reac

e compressible air within the flask, g it denser, increasing the specific of the whole apparatus until it be- greater than that of water, and it k. Take off your finger, and the air ask will expand, and again cause this *alloon* to rise. When very nicely , this toy may be made to float when t the surface, yet may be incapable g when thrust to the bottom.

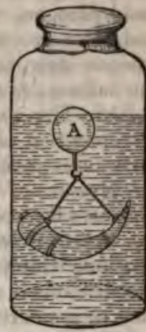

Fig. 191.

A common balloon is a great bag of rounded by a net of cord, carrying pable of holding one or more men. is gradually filled with hydrogen gas, h the specific gravity is only 1-13th great as air, until the specific gravity whole apparatus, together with the traveller or *aero-* d his baggage, becomes less than that of air. The

Fig. 192.

balloons is usually obtained by pouring diluted sulphu- l upon filings of iron in barrels, which causes a de-

ing upon it from below. The pump-handle is then de[
and of course the valve at D is instantly closed, so as to]
the return of the water. There is then more matter
chamber D than there was at first, and as this gives le
for the piston-rod, its pressure must be increased, and
tion of the air will be squeezed or driven out thro
valve in the horizontal canal, which readily opens to
passage, but closes again to prevent its return. Wh
pump-handle is again raised, more water is drawn i
chamber D, and by repeating this process two or thre
nearly all the air is expelled, and D becomes nearly
water. As the pump continues to work, a quantity o
equal to the size of the piston-rod enters the pump
every ascending stroke, and the same quantity is
through the horizontal canal into the great cylindrical
ber, at every descending stroke of the handle A. The
drical chamber being thus freely supplied with wat
screw K is tightened, and all escape from the cyli
thus prevented.

493. The machine is now ready for use. Any thi
we wish to subject to pressure is laid upon the iron t
and over it are placed planks, masses of iron, or we
any other character that possess sufficient strength, u
the space between the cross-piece M N and the bod
pressed is occupied by unyielding solid materials.
pump is then again set in motion, and as the cyli
chamber becomes gradually filled with water, the gre
cylinder G is forced upward, making pressure upon t
stance upon which we wish to operate through the med
the table F. When the resistance of the compressed sul
has become so great that the table F can rise no farth
pump is stopped; but still the pressure is maintained; b
the little spring-valve in the horizontal canal acts
powerfully upon the water in the cylindrical chamber
piston-rod of the pump had previously done. Thus th
may be continued until the screw L is relaxed.

494. We will now make a little calculation of th
of the Bramah press. Let the length of the pump-ha
be four feet, and the distance from the joint or fulc
the piston-rod six inches. By the law of the leve
multiplies the power eight times. If the entire wei
two men, each weighing one hundred and fifty pou
thrown into action upon this lever, the force acting up
piston-rod, neglecting the loss by friction, would be a
$300 \times 8 = 2400$ pounds. Now, the horizontal section

piston-rod in this case does not exceed one-quarter of a square inch; and upon this small surface the whole force of the lever takes effect. But forces applied to bodies of liquid are diffused equally through all parts of those bodies, and act equally in all directions. Therefore, the pressure on the surface of the chamber D with its valve, the horizontal canals with their valve and plug, the cylindrical chamber, and the great iron cylinder, is equal to 2400 pounds on each fourth part of a square inch, or 9600 pounds on each square inch. The portion of this pressure which tends to elevate the table F, is that which acts perpendicularly upward against the lower extremity of the cylinder G; and if the transverse section of this cylinder measure 64 square inches, the whole pressure exerted on the table F must amount to $9600 \times 64 = 614{,}400$ pounds, or 274 tons 5 cwt. 2 qr. 24 lb.

495. It is not difficult, with this machine, to bury a quire of paper into a wooden plank, and water has been forced by it through the pores of gold. It is said that the water from the cylindrical chamber sometimes appears in drops on the outside of its thick iron walls; as if the machine were actually perspiring with its excessive exertions.

496. Though liquids have naturally level surfaces when undisturbed, because their particles press equally in all directions, the surfaces of great lakes and seas are never absolutely level, because they are always disturbed, wholly or in part, by winds and other forces, which drive and pile up the water before them; but the liquid perpetually seeks to return to a state of rest by stealing off in any direction where the disturbing force does not act, or acts but feebly. This is the origin of currents, which perpetually tend to bring the fluid to its true level. The surface of the Gulf of Mexico is invariably higher than the surface of the North Atlantic, or the water on the opposite shores of Africa, because certain constant forces connected with the revolution of the earth, which we are not yet fully prepared to explain, keep the water piled up against the western shores of the ocean, within the tropics; but between the island of Cuba and the coast of Florida, these forces do not act to the same advantage; and here the water steals out of the gulf in a gigantic and rapid stream, sweeping northward along the coast of the United States. Blow with your breath across a large tumbler nearly full of water, and you will see a beautiful illustration of the nature and source of the causes of currents; for the whole surface will be converted into two equal and opposite whirlpools by the joint action of the wind and the shores of this *mimic* lake.

497. The equality of the pressure of liquids in all directions is productive of many other phenomena of great importance, and capable of being foretold by an acute reasoner, without the aid of experiment, when the laws of fluid pressure are well understood: but their dependence thereon is not so obvious to a mere tyro in the study of physics, and it is therefore necessary to give them special illustration.

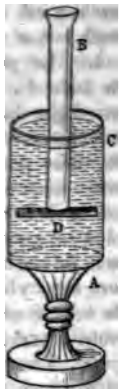

Fig. 189.

498. Let A be a glass vessel nearly filled with water or any other liquid; B, an open glass tube of moderate dimensions; C, the surface of the liquid: and D, a piece of metal, polished so as to cover the lower orifice of the tube and keep out the liquid, when applied. Let the weight of D be fixed:—say one ounce. Now, if B be held perpendicularly in the air, and D be applied as in the figure, the latter will fall off: for there is no force in action to resist its gravitation. If D be held in its place until the tube is lowered so that the metal may just touch the water, it will fall and sink by its weight, because the water cannot press upward against an object exactly on its own level. Let the tube and metallic plate be carried down a short distance below the surface, and then let D be left free. Still it will sink, because it still overbalances the upward pressure of the liquid in the basin. Now, let the tube and metallic plate be carried deeper into the basin, until the solid content of that part of the tube which is below the general surface of the liquid would hold, if filled from the basin, a weight of liquid exactly equal to that of the metallic plate, when the latter is above the surface. You will at once perceive that if D were now removed, the pressure of the liquid on the outside would force up a portion of liquid into the tube, which would fill it to the general level; that is, the upward pressure at D would support a weight of fluid exactly equal to that of D; or, in other words, *it would support the weight of D;* which, therefore, could not sink. Under such circumstances, the metal may be said to have lost all its weight, when the word weight is used in its vulgar sense. It *floats* against the end of the tube more lightly than a cork on the surface; yet a few drops of water quietly placed on its upper surface, within the tube, would instantly cause it to sink, by increasing its weight. If the tube were now driven still deeper into the liquid, the upward pressure would continually increase; the

the whole length of the graduated arm, by the portion over which W slides to restore the balance—that is, by dividing the weight in air, measured in feet, &c., by the difference between this and the weight in water measured in the same terms—we obtain the specific gravity of M. But this instrument is graduated by placing over each point on the scale the number expressing the quotient of the whole arm C B, divided by the distance between that point and the extremity B. Hence the series of numbers on the scale is a series of specific gravities, and by this instrument we have only to weigh any body first in air and then in water, using any other convenient body for a weight, and the position of the latter on the scale indicates the specific gravity of the former, without calculation.

521. To obtain the specific gravity of a solid lighter than water, first weigh the solid in air. Then take a piece of metal heavy enough to sink this solid, and having noted the weight of the metal in water, attach to it the light body, and weigh them together when immersed. The difference of these weights, added to the whole weight of the light body in air, will give the weight of a bulk of water equal in size to the light body. This, divided into the weight of the light body in air, will give the specific gravity.

522. The specific gravity of any liquid may be readily ascertained by weighing, when empty, a suitable vessel of which we know the exact contents in cubic inches, and then filling it with the liquid under examination and weighing it again. The weight of the cubic inch of water at 60° of Fahrenheit, being known, we can calculate the weight of water required to fill the vessel. Divide the weight of the liquid in the vessel by that of the water required to fill it, and the quotient will represent the relative weight or specific gravity of the fluid.

523. Many useful instruments, designed to determine the specific gravities of liquids, and occasionally employed for solids also, are known by the name of *hydrometers*. Some of these are used to ascertain pretty nearly the relative weights of liquids, without calculation; but as we have time to describe but a single example in this place, we shall choose one of the most general application.

524. In Fig. 196, A represents a thin bulb of glass, surmounted by a narrow stem, C; carrying upon its summit a light weighing scale, D, and ballasted by another heavier weighing scale, B, attached to it beneath. A mark is placed on the stem at E, and the instrument is so formed

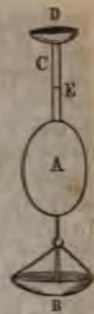

Fig. 196.

that when placed in water, and loaded until the mark at E is brought to the level of the surface, it shall displace exactly one thousand grains of water. The weight required to bring E to the surface, is ascertained by experiment. If this instrument, properly loaded, be placed in a liquid either denser or rarer than water, weight must be added to or subtracted from the scale D, in order to bring E to the level of that liquid; and this weight will measure the difference between the bulk of water which weighs one thousand grains and the weight of an equal bulk of the fluid under experiment. Add or subtract, accordingly, this difference from 1000 grains, and you obtain the weight of the displaced liquid. Then divide this last weight by 1000, and you obtain the number representing the specific gravity of the liquid.

525. Alcohol is specifically lighter than water, and the increase of specific gravity, when the latter is mixed with the former, bears a certain fixed proportion to the quantities of the two fluids thus mixed. From this fact you are able, by means of the hydrometer, not only to tell when wines or liquors are adulterated with water, but also to determine the quantity of admixture. The same means enables you to test the strength of ley, most solutions of salts, and a thousand other mixtures important in chemistry or domestic life.

526. To ascertain the specific gravities of airs or gases, we are obliged to resort to the use of the air-pump, an instrument which you will better comprehend hereafter. A glass vessel of known content is provided with a stop-cock, and this vessel is weighed when emptied of everything by the air-pump. It is then successively filled with air and other gases, and is weighed at each experiment. By deducting the weight of the empty vessel from each of these results, we obtain the weights of equal bulks of all the gases thus examined, and may then calculate their specific gravities when compared with any standard by the ordinary method.

527. You will now be able to understand any apparatus for ascertaining specific gravities or the relative densities of bodies, because you know that they are all intended to show how many times the weight of any one body contains the weight of an equal bulk of water or atmospheric air.

528. A simple apparatus, called a barometer, founded upon the upward pressure of fluids, enables us to ascertain the

weight or pressure of the atmosphere we breathe. Take a glass tube more than thirty-one inches long, and closed at one end, Fig. 197, A. Fill it completely with dry mercury, and invert its open extremity into a cup containing some of the same liquid metal, B. There is now nothing to prevent the mercury in the tube from descending into the cup and overflowing it, except it be some force outside of the tube, which supports it by an upward pressure equal to its weight. Yet it only descends an inch or two; as, to C; and there remains stationary. What supports it? It cannot be the mercury in the cup; for no liquid can support, by its upward pressure, any of its own particles that rise above its own surface: Yet, there is nothing else to produce an upward pressure in this case, except the atmospheric air resting upon the surface of the mercury in the cup, but which is prevented from pressing upon the mercury in the tube, by the inflexible glass. If a crack be made in the top of the tube, the mercury instantly descends, because then the atmosphere presses it upward and downward with equal force, and there is no force left to resist its gravitation. If you try the same experiment with a tube of India rubber, the mercury will not be supported; because the tube, being flexible, is pressed together or made to collapse by the pressure of the atmosphere, and the ascendancy of the upward pressure on the mercury is lost. It is plain, then, that the mercury is really supported in the tube by the pressure of the air on the mercury in the cup, and this pressure will support it at such a height that the weight of the column of mercury will just balance the pressure of the air without. This height has nothing to do with the form of the tube; because the pressure of fluids is alike in all directions; and if we compare the atmosphere to one branch of the tube in Fig. 193, and the barometer tube to the other branch, we shall perceive that the atmosphere and the mercury balance each other in this experiment, just as the mercury and liquid under trial do in the experiment given in paragraph 518. The height of the mercury in the barometer is therefore a measure of the pressure or weight of the atmosphere.

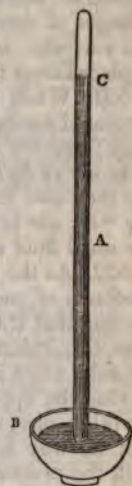

Fig. 197.

529. The mercury in the barometer varies in height from 28 to 31 inches, or even more widely, according to the state

of the weather, which proves that the atmosphere is denser or heavier at one time than it is at another, even at the same place, and the height of the mercury at different times measures these differences of pressure.

530. The barometer generally stands lower, or the atmosphere weighs less at any place, when the weather is stormy than when it is fair. This difference of pressure is often a cause of storms, because it disturbs the equilibrium of pressure throughout the entire atmosphere, and leads to the formation of currents or winds, in the same manner that partial changes of density in water lead to the formation of aqueous currents; as you may observe when a tea-kettle of water is placed over the fire to boil.

531. When the barometer is high, we feel braced by the increased atmospheric pressure both within and without the body; and we say, in direct contradiction to the truth, that "*the air is light*," because *we feel light*, in consequence of the increased support. But when the barometer is low, we say "*the air is heavy*," because *we feel heavy*, for want of the usual fluid support.

532. As the pressure of the atmosphere can only support a column of mercury which is just sufficient to balance it, we find that if the tube used in the last experiment be longer than this column, the mercury will subside from the top of the tube when inverted, until the metal finds its proper level, leaving the upper part of the tube empty. Neither air nor anything else, unless a little vapour from the mercury, can find its way into this space, which therefore furnishes us with the nearest possible approach to a perfect vacuum, that the art of man can produce.

533. Mercury is 13.57 times heavier than water, and hence the same pressure of the atmosphere is capable of supporting a column of water 13.57 times higher than that in the mercurial barometer; but if you were to fill an inflexible tube closed at one end, and more than 34 feet long, with water, and were then to invert it over a vessel of water, the fluid would subside to the height of about 34 feet, leaving the upper part of the tube empty, in the same manner as the mercury does in the barometer. This would be a water barometer, but it would be too long for convenient use.

534. You are now prepared to comprehend the action of the common pump for raising water. This hydraulic instrument, represented in section in Fig. 198, consists of a wooden or metallic trunk or tube, A, furnished with

577. The opposition offered to the motion of a body by a fluid depends much upon the form of the surface and the direction of its advance. If a flat body be moving directly against a fluid, the resistance from inertia is very great; and if obliquely, it is less in proportion to that obliquity; but it is unnecessary to enlarge upon this subject, for it is evidently regulated by the laws governing the action of solids upon inclined planes, modified by the peculiar conditions of the particles of different fluids. With those laws you are already acquainted; and the influence of these peculiar circumstances is much more readily determined by experiment and observation, than by reasoning and calculation.

578. The resistance from hydrostatic pressure is very much diminished when the moving body has a figure that facilitates the return of the particles in its rear after they have been divided in front. Ships and the most rapid fish are made rounding, though bold in front, to act with all the advantage of the wedge, scientifically curved in parting the water, while they are rendered more gradually sloping and taper behind, in order to allow the most ready return of the fluid to renew the hydrostatic pressure in the rear. If a ship were divided at her waist, and the front part furnished with a flat stern, it would sail with the utmost difficulty, leaving a deep trough in rear; and if a flat board be placed athwart the bows of a vessel, she advances no faster than she can move sideways, when properly constructed; because this board acts upon the water in the manner of a keel. A body with a concave surface is found to move through fluids with even greater difficulty than one that is perfectly flat: hence oars and paddle-wheels are sometimes made concave to increase resistance.

579. The question of the best form for ships or other machinery designed to answer a given purpose with the least possible resistance from fluids upon which they act or re-act, is one of great importance, but so complex that it is still a matter of experiment as well as theory. You will not be surprised to hear, then, the apparent contradictions that a vessel with small sails may exceed in speed a similar vessel with larger sails, or that one ship may outstrip another with a light wind, yet be overhauled and passed by her, under a heavier breeze. In fact, no artisan can apply a greater extent of physical science to useful purpose than the navigator in advising with the ship-builder, the stevedore, and the sail-maker, and in commanding his helmsman, and his mates. If you bear in mind that the resistance of a fluid

it no longer counterbalances the pressure of the atmosphere on the water in the cistern or pool, and a column of water rises into the bottom of the pump-tube, to a height sufficient to restore the balance of atmospheric pressure within and without. This column of water forces up the valve of the lower bucket, F, and a portion of it rushes through the hole. When the handle is again raised, the valve at F is immediately closed by its own weight and that of the water above it, while the valve of E is again blown open by the pressure of the remaining air beneath it, now occupying less space, in consequence of the water that has ascended through the lower bucket. At each downward stroke of the pump-handle, an additional quantity of water is forced upward into the tube, by the pressure of the atmosphere without, until the bucket E begins to descend beneath the level of the water, when the handle is raised. A portion of the water is then forced upward, through the valve at E, at each elevation of the handle, and is prevented from returning during the downward stroke, by this valve; so that it must be lifted up as the handle descends, and must finally escape by the pump-spout C.

536. A pump of this construction cannot act when the distance between the bucket E and the surface of the water in the pool or cistern is greater than the height of the column of water which can be supported by the pressure of the atmosphere, and it is found to be practically of little use when this distance is greater than twenty-two feet.

537. Although the direct order of our studies should now call us off to other subjects, it may perhaps promote the interest of the pupil to describe in this place the forcing-pump and the air-pump, because their mechanical construction so closely resembles that of the common pump.

538. The common forcing-pump is seen in section in Fig. 200, where the letters, with the exception of A, have the same value as in Fig. 198. The handle, B, is usually a lever of the second order. The bucket, E, is changed into a simple piston, without any valve. When the piston is lifted, water rushes up through the valve in F, as in the common pump, but when the piston descends, this water cannot penetrate E, which has no valve, nor can it pass back through F, the valve of which is instantly closed. It is therefore forced into the spout C, through a valve above G, at the lower end thereof, which opens towards the spout to allow the water to flow into it, but instantly closes and retains it, when the piston is again raised. In this manner more water is forced

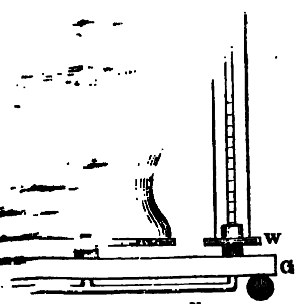

Fig. 201.

metallic plate, W. The main
a little valve, and communicates
n orifice which may be opened
y means of a thumb-screw at F.
passing through the plates K and
with air-tight caps, which are taken

ing, and its *matter* exercising pressure upon the surrounding water equally in all directions. Therefore; as column after column of particles subsides on the surface next the pebble, a similar number of columns must rise from the general level towards G and F, under the action of this pressure, and thus the *figure* of the wave rolls on to F G, followed by the circular groove, D E, created in the same manner by the descending columns of the same wave in rear and the rising columns of the new central wave, L. The figure, I say, rolls onward, but the matter of the wave simply vibrates upward and downward, without any onward movement. You can now understand why two waves meeting each other may ride over each other without interfering, and continue their several routs. Throw a handful of pebbles into a quiet lake, and you will produce a multitude of waves in concentric circles, moving off from many centres, and intermingling in seeming confusion but real order. You are now also able to comprehend the reason why heavy waves roll towards the shore in calms, or even in direct opposition to the wind; and why a high swell often informs the mariner of the occurrence of a gale at a distance of a hundred miles, while, perhaps, his vessel is rolling her masts out upon the surface of a heaving ocean, glassy in smoothness, and unruffled by a breath of air.

582. When a liquid is already in a state of undulation, and another force gives rise to a new local depression or elevation, the newly-formed waves may be said to regard the actual surface at each moment as if it were the permanent form of the surface; and they proceed in the same order over the pre-existing waves and furrows as if the liquid were at rest. Hence one wave may become piled on another, and one furrow may be grooved out at the bottom of another, so as to increase the height and depth of the apparent waves. Thus, when two equal waves meet in such a manner that the summit of one is distant from the other by exactly the length of either wave, measured from the bottom of one furrow or *trough of the sea* to the bottom of the next, the height of the swell is doubled at the moment of their coincidence.

583. But, on the other hand, though the matter contained in waves is impermeable, the forms or figures which we call waves are not material, being only composed of variable spaces, defined for the moment only, by matter in a state of motion; and they are therefore perfectly permeable, as all spaces are permeable. Hence, if one wave meet another in

as fast as they abstract it from M; and, as the pressure of the air remaining in M will be measured by the height of the mercury in the barometer, P, which is measured by means of a graduated scale marked on the tube, you can ascertain at all times, by this means, how perfect the vacuum in the receiver of an air-pump may be.

542. We often wish to try experiments with atmospheric or other fluid pressure, greater than that of the air in its common condition. Thus; fluids boil at a much lower temperature when there is little pressure on their surface than when the pressure is great. The law according to which the pressure of the atmosphere diminishes as we ascend, enables us, with care, to calculate the height of mountains by ascertaining the boiling points of water at their base and their summits. Ether boils and becomes a gas at the ordinary temperature of the air, when placed in a vacuum. It even absorbs heat enough, while boiling under the receiver of an air-pump rapidly exhausted, to freeze water on which it is floating. On the contrary, water may be heated, under great pressure, without boiling, to a point far above the red heat of iron. Papin's digester, with which the cook makes soup from the hardest bones, acts upon this principle. For the purpose of trying experiments on this subject, we often use *condensers* or *condensing-pumps*. The simplest of all condensers has been already figured and described (157). By using any instrument like the common forcing-pump, making its spout to deliver the fluid into a closed vessel, we convert it into a condensing-pump. Such an instrument, used for condensing water, is seen attached to the Bramah press, Fig. 188, p. 222. No change in its structure, other than an increased delicacy of its valves, would be necessary to convert it into a condenser for gases. In the summer time, any manufacturer of mineral water can show you such a pump in action, to force carbonic or other gases into the water in the cisterns, from which it bubbles up the instant the fluid is relieved from the unusual pressure, by turning the stop-cock.

543. Forcing-pumps on a large scale are usually so constructed that the piston delivers water with both strokes, and a condensing air-vessel is usually attached to their spouts or delivering-tubes, in order that the stream may be kept in regular flow by atmospheric elasticity; thus preventing the jerking of the machinery as effectually as a fly-wheel, and making the pump deliver water steadily, instead of doing so by fits and starts. You will better understand this operation

of condensing vessels, when you read, in the next chapter, the description of the water-ram.

544. Here let us return to the subject of fluid support, from which we have been partially drawn off by our remarks on pumps.

545. When a concave body, such as a ship or a boat, is placed upon the surface of a liquid, it displaces a quantity of that fluid equal in weight to the body itself, and any load that may be placed in it. If the weight of the boat, Fig. 203, be 5 cwt., and her load be a ton and three quarters, her floating in smooth water depends entirely upon her form being such as to displace two tons of water before her gunwale sinks to the level of the liquid. In rough weather she would sink long before she could be so deeply laden, because her changes of position, and the inroads of the waves, would continually increase her burden until she would be rendered specifically heavier than the liquid on which she reposes.

546. When boats, or similar bodies, such as logs, planks, &c.,—which may be looked upon as so many boats loaded full of matter lighter than water,—are floating upon the surface of a liquid, they always assume some particular position, and retain it as long as the form of the boat and the arrangement of the load remains the same. If any temporary force, such as the wind or a wave, turns them from their proper position, they instantly struggle to resume it on the cessation of the force. Let us inquire into the nature of these facts.

547. You have been told that all forces act upon any body precisely as if they had been applied in the same direction, and with the same intensity, to the centre of gravity of the body. Now, the liquid in which it swims, supports a boat with its load, exactly in the same manner as it previously supported the water displaced by that boat: But it previously supported the water displaced by the boat precisely in the same manner as it would have done if the whole of that water had been concentrated in its centre of gravity, and the buoyant force had been applied directly thereto. Thus the boat floats as if it were supported on a pivot or fulcrum placed at the centre of gravity of the displaced water; and this centre is therefore called *the centre of buoyancy*. This centre, however, is not a fixed point, except when the floating body has a spherical or elliptic form; for, every change of position in a floating body of any other form changes the figure of the displaced water, and consequently alters the position of its centre of gravity. Consequently, the ideal pivot formed by the centre of buoyancy, must be regarded as

variable point of support, the position of which may be easily determined in any given attitude of the floating body.

548. As the boat or floating body can change its position on the application of the slightest force, in consequence of the mobility of the liquid on which it swims, it moves about the centre of buoyancy under the action of any force, as a perfectly balanced lever or scale-beam moves about its fulcrum; and the influence of gravity regulates its position as it regulates that of a scale-beam. But when a body is free to move under the force of gravity, the centre of gravity of that body will always take the lowest possible position, and the centre of gravity of the boat and load therefore seek the lowest possible place, while the whole mass remains suspended on the centre of buoyancy by the upward pressure of the liquid. If, then, the boat be so loaded that the centre of gravity of the whole mass agrees exactly with the centre of gravity of the displaced fluid, the force of gravity will act directly upon the fulcrum formed by the centre of buoyancy, and can have no tendency to change the position of the boat. As a breath may turn the heaviest scale-beam when the fulcrum is placed exactly at its centre of gravity, so the breath of a child would overturn a frigate if it could be so loaded that the two centres should always agree. The form of ships and boats is such, however, that the centre of buoyancy is continually changed as they change their position, while the centre of gravity of the vessel and its load remains always the same, unless the load be shifted; so that, in every vessel, there must be some position in which, if she do not sink, she will remain at rest, in perfectly smooth water. As in the case of solid bodies lying on a plane, this state of rest is obtained, only when the centre of gravity is directly over or directly under the point of support; which, in this case, is the centre of buoyancy.

549. Let Fig. 203 represent a boat, of which the centre of buoyancy is designated by the upper of the two large dots in the figure, and the centre of gravity of the boat itself by the lower large dot. If the latter be directly beneath the former, the boat will be at rest. But, if other forces than gravity, such as winds or waves; throw her for a moment into a new position, as long as she takes in or

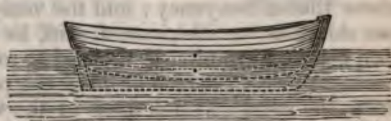

Fig. 203.

ships no water, she struggles to resume her former attitude; because her centre of gravity is thereby necessarily elevated, and endeavours to re-descend. If, however, the centre of gravity of the boat and cargo be placed above the centre of buoyancy, the moment the equilibrium of the boat is destroyed, the former will endeavour to descend; and unless the form of the boat so changes the position of its centre of buoyancy as to bring it once more directly over its centre of gravity before the boat begins to take in water, it must inevitably be overturned.

550. When the weight composing the load of a vessel is shifted, the centre of gravity of the vessel and load is also changed. Thus; suppose that a passenger in a well-trimmed skiff moves nearer to either side of the boat; the centre of gravity necessarily follows his movement to a certain extent, and must then continue to revolve until the centre of buoyancy is again brought directly over it; and the skiff will lean, perhaps dangerously, towards the side on which the passenger is sitting.

551. If the cargo be made of very heavy materials, crowded near the keel, the centre of gravity of the vessel may be so far below the centre of buoyancy as to make her very firm in her position; yet, when pitched by the waves, or caused to lean to one side by gusts of wind, she is then jerked back to her former place suddenly and with violence, in consequence of her weight acting at a considerable distance from the fulcrum or centre of buoyancy. This suddenness always strains and racks the timbers, and may even break the masts. On the contrary, when the load is too light specifically, or placed too high up in the hold, the centre of gravity coincides so nearly with that of buoyancy, that the vessel is in danger of being overturned by very slight forces, and, in a calm, not unfrequently "rolls her masts out" by centrifugal force. If the load be still less dense, or be raised altogether too high, the position of the centre of gravity may be raised above that of buoyancy; and the vessel will either lean on one side, like an ill-trimmed skiff, lie on her beam-ends, or turn bottom upwards. If the load be so placed as to bring the centre of gravity behind or *abaft* the proper centre of buoyancy, the stern will sink deep in the water, while the bow will rise proportionally high. If, on the contrary, the centre of gravity be brought *ahead* of that of buoyancy, the bow will sink, and the ship will appear, in nautical phrase, "like a duck in a gale of wind."

552. From the foregoing remarks, you perceive that all

the results of the action of winds, cables and anchors, currents, &c., on the attitude of vessels in the water, are capable of being explained upon the principle of the lever; the centre of buoyancy at the moment being the fulcrum thereof.

553. With these remarks, we close our elementary labours in hydrostatics.

CHAPTER V.

HYDRAULICS.

554. *Flow of Liquids along Pipes.*—Most of the principles involved in the flow of liquids along pipes of considerable length, have been fully explained in former chapters; but a few words on the application of these principles to practice, in the ordinary affairs of life, may be proper here. When a tube, closed at one extremity, communicates with a reservoir of water, which fills it completely, the pressure is diffused, as in all other vessels, according to the law that the pressure of liquids increases directly as their depth. When the extremity of the tube is opened, as when the stop-cock of a hydrant is turned, all resistance to the flow of the liquid under this pressure would cease, were it not for the friction of the liquid against the sides of the tube, as the column moves forward to make its escape, and the friction of the particles of water against each other. Let Fig. 204 represent the ends of two long tubes delivering water from open orifices. The water at the extremity, A, of the horizontal tube will yield to the force of gravity, and flow out so readily as perhaps to leave the tube partially empty near this spot; yet, owing to the friction, which prevents the water nearer the reservoir from following so fast, the greater part of the tube may remain full, and the pressure on the pipe may increase as it approaches the reservoir, though the depth of the liquid remains the same. Bubbles of air are then apt to get entangled in the end of the pipe, in consequence of irregularities or waves on the surface of the flowing water, and these cut off the current more or less

Fig. 204.

completely, from time to time, causing it to gurgle or flow by fits and starts. If we wish a long, narrow tube to deliver water regularly in the horizontal direction, when the head or depth is not great, the orifice must be contracted, to prevent the admission of air. If the end of a long pipe be turned up, as at B, Fig. 204, this precaution is not necessary; but the friction in the tube may be so great as to cause the water barely to overflow gently, as represented in the figure, however great the head of water in the reservoir may be. The pressure will then be increased in the tube, as it approaches the reservoir; as in the former case; and that which acts at the extremity B must be measured, not by the depth of fluid in the reservoir, but by the height to which the water spouts. If we wish to make a respectable fountain with a long tube, we must make it as large as possible, and contract the orifice. Even then it cannot be made to spout as high as the surface of the reservoir from which it comes.

555. Through tubes that are very long and narrow, water will scarcely flow at all; nor would it, even if capillary attraction did not exist. Even air produces so much friction in narrow tubes, that, with a bellows having a small nozzle some feet in length, you cannot blow out a candle.

556. When a liquid is once in motion, it acquires momentum in the same manner as a solid; and this momentum cannot be suddenly stopped without great force. Thus, when a hydrant is running, if you turn the stop-cock very quickly, the water, by the check of its momentum, jars the pipe severely, producing a loud noise, and endangering the bursting of the pipe. When the top of even a small wave, at sea, is driven directly against the side of a ship, she trembles in every timber from the blow. This principle has been beautifully applied in a hydraulic machine for raising water, of which you see a view in section at Fig. 205. A, represents a reservoir or stream of water; B, a tube leading from it, and descending to a closed extremity at C. D is a short tube, entering the side of the main tube B, and provided, within the

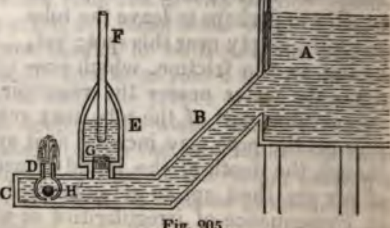

Fig. 205.

577. The opposition offered to the motion of a body by a fluid depends much upon the form of the surface and the direction of its advance. If a flat body be moving directly against a fluid, the resistance from inertia is very great; and if obliquely, it is less in proportion to that obliquity; but it is unnecessary to enlarge upon this subject, for it is evidently regulated by the laws governing the action of solids upon inclined planes, modified by the peculiar conditions of the particles of different fluids. With those laws you are already acquainted; and the influence of these peculiar circumstances is much more readily determined by experiment and observation, than by reasoning and calculation.

578. The resistance from hydrostatic pressure is very much diminished when the moving body has a figure that facilitates the return of the particles in its rear after they have been divided in front. Ships and the most rapid fish are made rounding, though bold in front, to act with all the advantage of the wedge, scientifically curved in parting the water, while they are rendered more gradually sloping and taper behind, in order to allow the most ready return of the fluid to renew the hydrostatic pressure in the rear. If a ship were divided at her waist, and the front part furnished with a flat stern, it would sail with the utmost difficulty, leaving a deep trough in rear; and if a flat board be placed athwart the bows of a vessel, she advances no faster than she can move sideways, when properly constructed; because this board acts upon the water in the manner of a keel. A body with a concave surface is found to move through fluids with even greater difficulty than one that is perfectly flat: hence oars and paddle-wheels are sometimes made concave to increase resistance.

579. The question of the best form for ships or other machinery designed to answer a given purpose with the least possible resistance from fluids upon which they act or react, is one of great importance, but so complex that it is still a matter of experiment as well as theory. You will not be surprised to hear, then, the apparent contradictions that a vessel with small sails may exceed in speed a similar vessel with larger sails, or that one ship may outstrip another with a light wind, yet be overhauled and passed by her, under a heavier breeze. In fact, no artisan can apply a greater extent of physical science to useful purpose than the navigator in advising with the ship-builder, the stevedore, and the sail-maker, and in commanding his helmsman, and his mates. If you bear in mind that the resistance of a fluid

by its inertia, acts as if the whole force were acting at its centre of resistance or percussion;—that the hydrostatic pressure acts directly as the depth;—that projectile force and gravity act as if concentrated in the centre of gravity, and the buoyant force impressed upon floating bodies acts as if concentrated at their centres of buoyancy, you will perceive how completely questions of fluid resistance are regulated by the laws of the pressure and impact of solids, and will have no more difficulty in understanding the effect of a stream in turning a water-wheel, the wind in driving a sail, or a sail in driving a ship, than in calculating the motion of a pendulum, the resolution of the force exercised by one billiard-ball upon another, the overturning of a carriage on the hill-side, or any question involving the laws of inertia, the inclined plane, and the lever; except so far as it is more difficult to understand the effects of a great many little bodies (particles) than those of a single large body. Most of these questions, indeed, may be determined mainly by the resolution of forces and the law of the lever, if we neglect the effects of fluid cohesion and friction, which compel us generally to correct our theory by experiment.

580. *Of Waves.*—When a pebble is thrown into a pond, it not only depresses the column of water upon which it strikes, but thrusts aside part of the water which it displaces. The inertia of the water beyond the immediate influence of the blow, prevents the particles from moving freely in a lateral direction, to allow room for the pebble, and they therefore become piled up on all sides, by the action of the two opposing forces, and are compelled to assume the form of a

Fig. 212.

circular wave. Let the dark line, I K, Fig. 212, represent a view in section of a fluid surface beneath which a pebble has just disappeared at C. The pit formed at this point then represents the depression of the column on which the pebble fell, and the round elevations, A and B, are views in section of the circular wave thrust aside by it; neither of which, in the first instance, changes perceptibly the general level of

he water marked by the horizontal parts of the dark line, I K. Now, it is evident, from the laws of fluid pressure, that every particle in the wave, A B, which is above the level, must fall by gravity when the disturbing cause ceases to act, and that every particle at the surface of the little pit, C, must rise by the hydrostatic pressure of the fluid around it. Let the black dots at A and C represent two particles; one in the wave, the other in the pit. By the laws of gravity, the particle A will fall with increasing velocity till it reaches the general level; but, by the laws of momentum, it cannot stop there: it must continue to fall with a retarded velocity, until its acquired momentum is lost in overcoming the upward pressure of the increasing column of water above it; and this is only accomplished (friction and atmospheric resistance excepted) when it has fallen as deep below the surface as it was previously raised above it. For precisely similar reasons, the particle C must rise to an elevation equal to its previous depression. Thus each particle in a wave has a tendency to vibrate like a distinct pendulum; and hence, in a few moments, the depression becomes an elevation, and the elevation is changed into a depression, as represented by the dotted line in the figure at L, D and E. It is evident that this vibration would continue without end, were it not that atmospheric resistance and other causes soon destroy the vibratory motion, and bring the water to rest.

581. The motion of the water in waves, when undisturbed by other causes than the momentary forces producing them, is therefore almost exclusively an upright, and not a progressive motion. Why, then, do waves, raised by a pebble, appear to roll outwards, in concentric and spreading circles, until they cease to rise perceptibly above the surface in consequence of the increase in width and diminution in height caused by friction and atmospheric resistance? This difficulty will at once disappear when you consider that the particles immediately around the pebble or any other depressing force are first thrown up above the general level, the more distant columns of molecules being elevated successively, until the whole of the first wave is formed. But the column nearest the centre, which is the first to rise, must also be the first to sink, and no column can sink without some other corresponding column rising to make room for it. Therefore, all the particles on the side of the wave next its origin must be subsiding at all times, while those on the opposite side must be constantly moving upward. Moreover, while the pit C is being filled up, the *figure* of the wave, A B, is sink-

into place. All these retarding causes obviously act most powerfully upon the tallest fountains; so that, in fact, the less the depth of water in the reservoir above an outlet, the nearer will a fountain approach the height of its source; and this difference between the abstract law of simple velocity and the practical result, enables us to determine, by experiment, the influence of friction, atmospheric resistance, and other causes, when affecting the motion of fluids, much more easily than we could discover the laws governing the action of those causes by mathematical calculation.

563. When water rushes out at a simple orifice in the bottom of a vessel; as at A, Fig. 207; it rushes in all directions towards the orifice, in the manner represented by the curved lines in the figure. The particles coming in laterally, acquire a velocity which cannot be stopped instantly on reaching the orifice, and they struggle to cross over and spread themselves out on the opposite side; clashing with and increasing the friction of other particles. But, as their motion is oblique, a part of it has the effect of urging the current downwards, as you will at once perceive by resolving the force of a single particle into a horizontal force and a vertical one. Nor is all the horizontal motion lost in the conflict. The results of the combined forces of all the particles cause the liquid, in the first place, to move more and more rapidly for some time after leaving the orifice; consequently, rendering the stream narrower continually to a certain distance; and, secondly, to spread itself out into a conical form, below this point. The form of the stream is seen in the figure. The position and relative dimensions of the narrowest point vary with the form and size of the orifice.

Fig. 207.

564. The motion of a jet is occasioned by the pressure of the liquid in the reservoir from which it issues. But when one body is put in motion by the action of another body, the former must react to an equal extent upon the latter. Hence, when a jet issues from any orifice in a vessel, the vessel, with its contents, if free to move, is driven in the opposite direction, with a force equal to that with which the fluid escapes. If a boat were made to carry a large reservoir of water on her deck, and a hole were bored in the hinder part of this reservoir, the boat would be immediately propelled forward by the reaction of the jet: if the rapidity of the flow were increased by artificial pressure upon the reservoir, the velo-

of the boat would be proportionally increased. If a boat were provided with a pump drawing water from ottom, and throwing it out through her stern, beneath ırface, she might be propelled across a river by simply ing the pump.

5. This motion from the reaction of escaping fluids is means confined to liquids. But a few years have d since the heavy boiler of a Philadelphia steam ferry- eaped from the vessel into the river, carrying with it hole of the machinery and the deck also, leaving the y hull still floating. This accident was occasioned by scape of steam from a rent in the bottom of the boiler.

6. Upon this principle of the reaction of a current or he mill known as Barker's is constructed. The moving r is thus obtained. A hollow der of iron, A, is made to re- in a stout frame, as repre- d in Fig. 208. Near the sum- of the cylinder is a funnel- d expansion, communicating the cavity. Into this funnel ater used for turning the mill ured by means of a pipe or h, B. The funnel is sur- ited by an arbour, usually ng a drum-head or cog-wheel, hich communicates motion to nachinery. Near the lower mity, the cylinder is provided one or more pairs of hollow their cavities communicating its main tube. These arms

Fig. 208.

rranged like the spokes of a wheel; and at their outer mities they deliver each its jet of water in the direction tangent to its circle of revolution, and towards corre- ling sides of the arms. The cavity of the cylinder kept constantly full from the pipe B, the arms, cy- r, and drum-head are made to revolve by the reaction of jets. This is found to be an economical mode of apply- ater-power in many situations, where the head of water at. You will at once perceive, on inspection, that the ving gas-lights which ornament our shop-windows are motion in a similar manner. The gas is held in a re- ir like an inverted tub floating in a larger tub of water;

and from within the former, the gas-pipes are led away to the residences of the consumers. By loading the floating tubs with weights, the pressure, and consequently the velocity of the jets, may be increased to any required extent. The brilliant wheels so often seen in fireworks revolve on the same principle; the gas generated by the burning powder, escaping in jets, in the direction of tangents to the circumference.

567. When an orifice is made in the bottom of a vessel containing any liquid, the column of the fluid immediately over it is less effectively supported than the rest of the fluid: but the pressure of the atmosphere being the same upon all parts of the surface, it must have somewhat more effect upon the part thus less sufficiently supported; and this part will therefore become depressed, until the greater height of the surrounding water produces upward pressure enough to supply the deficiency of support beneath the sinking column. While the liquid in the vessel is deep, the water flows in laterally towards the orifice so readily, and acts at such advantage, as to render this *imperceptible;* but as it becomes shallower, the lateral supply acts at less advantage, and the depression appears, at first, as a conical pit, and then as a funnel-shaped whirlpool. The atmosphere encroaches more and more upon the falling water, until it passes through the orifice; occupying its axis, and presenting the appearance represented in Fig. 209. When the air penetrates permanently beyond the narrowest part of the jet, the stream becomes hollow throughout, and soon takes the character of a mere drainage. The gurgling noise that usually attends the latter part of this emptying process, is occasioned by waves which occasionally fill the airy funnel for a moment, thus suddenly interfering with the momentum of the molecules; and the whirling motion is determined by the irregular action of the particles upon each other, as they crowd towards the opening, which, when they have once acquired a lateral motion in either direction, preserve it by their acquired momentum, and compel others to follow by their friction and cohesion. Everything in physical nature,—however seemingly trivial,—is governed by fixed rule, and subject to calculation.


Fig. 209.

568. If a short tube descend from such an orifice as that represented in Fig. 209, the contraction of the stream as seen in Fig. 207 cannot take place, because this would require

the formation of a vacuum between the fluid and the tube, which is prevented by the pressure of the atmosphere acting both on the surface of the liquid in the vessel and on that at escaping from the orifice; thus keeping the tube always filled. But, in preventing the formation of such a vacuum, the atmospheric pressure actually overcomes the horizontal portion of the momentum of the molecules in the orifice, thus lessening the conflict of particles in making their escape. Such a tube, therefore, will empty a vessel more rapidly than a simple orifice of the same form and dimensions. It is found, however, that if the tube project within the vessel, the entrance of the fluid is retarded, and the vessel is emptied more slowly.

569. The pressure of the atmosphere acts in the same manner in preventing any separation of the column of fluid contained in all tubes of moderate size, so that the whole mass must move together in compact column, when contained in such canals. In upright or inclined tubes, the disposition of a column of liquid to descend, being dependent on its weight, will be greater in proportion to its length. These two facts will enable you to understand the simple and convenient instrument called the syphon, used for emptying vessels through orifices situated in their summits instead of their inferior portions. Fig. 210 represents a syphon in action. It consists of a bent tube, A, B, C, having one arm considerably longer than the other. It is usually supplied with a smaller short tube, D, close to the extremity of the longer arm, for a purpose to be presently explained. When used, the extremity of the short arm, A, is plunged into the liquid to be drawn from the vessel; and the

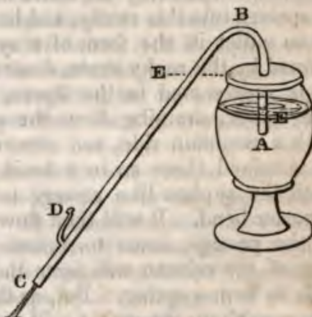

Fig. 210.

longer arm being carried downward below the level of the fluid, its orifice, C, is closed by a finger, and the mouth is applied to the little tube at D. By a continued effort of suction, a considerable portion of the air in the closed syphon is drawn out, and what remains having insufficient elastic force to resist the pressure of the atmosphere on the surface of the liquid in the vessel, this is driven upward into the

tube until it reaches the bend, B, flows over, and fills the long arm. The finger is then removed. There are now two columns of water in the two arms of the syphon, both tending to fall by their gravity. The liquid between A and the level of the surface at E, is exactly balanced by the hydrostatic pressure of the liquid in the vessel; but the column from E to B endeavours to fall back into the reservoir, while that from B to C endeavours to fall out at the orifice, C. The pressure of the atmosphere prevents the two columns from parting at B, which would create a vacuum; and, consequently, the longer column overbalancing the shorter, the latter is compelled to follow the motion of the former,—while, for the same reason, the fluid rushes from the vessel into the tube at E, to supply its place. Thus, a current proportional to the difference between the perpendicular height of B E, and B C, is completely established, and the vessel is emptied.

570. Intermitting springs and wells are best explained upon the principle of the syphon. Let Fig. 211 represent the section of part of a mountain, containing a cave or basin within it, capable of holding water. Also, let numerous crevices in the rock or soil above, convey the water of rains or springs into this cavity, and let there be an outlet in the form of a syphon, formed by the rocky strata, descending, as is represented in the figure, to A. The water, draining from the soil of such a mountain side, and descending into the cavity, will be detained there as in a basin; nor can it find an outlet until the syphon-like passage is filled with water up to its superior bend. It will then flow over and fill the remainder of the passage, down to A, and there the hydrostatic pressure of the column will force the water upward through the soil, to form a spring. But, as this passage plays the part of a true syphon, the spring will not cease to flow until all the water in the cavity is drained away. Then the flow must cease; nor can it be renewed until the cavity becomes filled again by fresh collections of water from above. Such a spring may flow very frequently during the spring and fall, and seldom, if at all, in the middle of summer. The phenomena of ebbing and flowing wells, and the irruptions of steam and boiling water, such as occur regularly in the hot springs of Iceland, may be explained on this principle, and may be imitated by art.

Fig. 211.

571. The common hydrant, in cities, becomes a syphon under certain circumstances. Its valve, which is opened or closed by the handle and a long upright connecting rod, is placed low beneath the soil, to secure it from frost in winter, and to prevent the pipe from being burst by the freezing of the water which fills it when in action: this water is drawn off by means of a small orifice near the valve, which is closed when the valve is open, and opened when it is closed, and which thus drains the pipe into the surrounding soil. If you draw a glass of water from such a hydrant, and keep the curved nozzle immersed in the fluid after you have stopped the flow, the water will be taken back by the tube, and the tumbler will be emptied; as if the hydrant itself were endowed with the power of drinking.

572. *Impact between Solids and Liquids.*—The impact between solids and liquids is governed by the same laws that govern the impact of solids, which have been already explained. When any solid body advances against a fluid, the resistance resulting from the inertia of the fluid varies as the square of the velocity; because, in doubling or tripling the velocity, the body strikes twice or three times as many particles in the same time, and strikes each particle twice or three times as hard; and the resistance, therefore, becomes four or nine times greater. By this law, if one hundred weight of coals will raise steam enough to drive a boat at the rate of two miles per hour, for twelve hours, it will require nine hundred weight to drive her the same distance in four hours, and thirty-six hundred weight to bring her to the very ordinary speed of twelve miles per hour for the same length of time.

573. But inertia is not the only force to be overcome when a body moves through a liquid: it is also opposed by hydrostatic pressure. While an immersed body is at rest, the liquid presses equally upon it in all directions; but the moment it begins to move, the pressure behind is diminished; for this can only be kept up in consequence of the liquid driven aside by the body coming together in its rear so as to react upon it. This reunion is effected only by the communication of motion to particles at rest, or by a change of direction in those already moving, which requires the application of force. The force that closes the liquid behind the body is the hydrostatic pressure of the liquid itself. Now, all that portion of the hydrostatic pressure which is expended in giving momentum to these particles, is lost in its effect upon the body itself, while that which acts in front of the

moving body loses none of its energy. It therefore requires more than the square of the force in action to double the velocity of a boat, and this law soon limits the increase of speed with which such machinery can be propelled by art, by bringing the required force to a point which the material of the machinery will not endure without being crushed.

574. Bodies may be made to move so rapidly through water as to exceed the speed with which the particles can follow or close in laterally behind them. There is, then, of course, a vacuum formed in their rear; and they are compelled to conquer not only the inertia of the liquid before them, but, in addition to this, the entire hydrostatic pressure of the column of the liquid in which they are immersed, added, in most instances, to the pressure of the atmosphere resting upon it.

575. This increased resistance from hydrostatic pressure is not confined to bodies moving in a liquid: a cannon-ball experiences it in the air, and may pass so rapidly that even that light fluid fails to close up behind it in time to prevent the formation of a vacuum. It is found practically useless to discharge shot from cannon with a velocity greater than 1200 feet per second, because the velocity beyond that measure is almost immediately destroyed by the tremendous resistance of the air. Gases being compressible to a great extent, must be crowded before bodies in rapid motion, so as greatly to increase the resistance, in consequence of the elastic reaction of the air thus compressed between the moving body and the fluid which lies farther from it, and of which the reaction is not yet overcome. That the inertia of the particles, at some distance in advance, though acted upon by the pressure of the approaching mass, is not instantly or immediately overcome, is obvious from the fact, that the current produced by the motion is scarcely perceptible in front, but is very powerful behind the moving body. This latter rule applies to liquids called inelastic, as well as gases.

576. The influence of hydrostatic pressure in opposing the motion of bodies, is beautifully displayed by the effect of a steamboat passing rapidly along a narrow river. By studying the actual piling up of the water in front; the direction and causes of the waves that spread out from the bow and the waist of the boat, finally breaking upon either shore; the agitation of the water behind the stern, and the pursuing current in the wake, together with the course and influence of the great swells thrown up by the paddles, you *may see* developed a multitude of interesting problems in *hydrostatics* and hydraulics.

577. The opposition offered to the motion of a body by a fluid depends much upon the form of the surface and the direction of its advance. If a flat body be moving directly against a fluid, the resistance from inertia is very great; and if obliquely, it is less in proportion to that obliquity; but it is unnecessary to enlarge upon this subject, for it is evidently regulated by the laws governing the action of solids upon inclined planes, modified by the peculiar conditions of the particles of different fluids. With those laws you are already acquainted; and the influence of these peculiar circumstances is much more readily determined by experiment and observation, than by reasoning and calculation.

578. The resistance from hydrostatic pressure is very much diminished when the moving body has a figure that facilitates the return of the particles in its rear after they have been divided in front. Ships and the most rapid fish are made rounding, though bold in front, to act with all the advantage of the wedge, scientifically curved in parting the water, while they are rendered more gradually sloping and taper behind, in order to allow the most ready return of the fluid to renew the hydrostatic pressure in the rear. If a ship were divided at her waist, and the front part furnished with a flat stern, it would sail with the utmost difficulty, leaving a deep trough in rear; and if a flat board be placed athwart the bows of a vessel, she advances no faster than she can move sideways, when properly constructed; because this board acts upon the water in the manner of a keel. A body with a concave surface is found to move through fluids with even greater difficulty than one that is perfectly flat: hence oars and paddle-wheels are sometimes made concave to increase resistance.

579. The question of the best form for ships or other machinery designed to answer a given purpose with the least possible resistance from fluids upon which they act or react, is one of great importance, but so complex that it is still a matter of experiment as well as theory. You will not be surprised to hear, then, the apparent contradictions that a vessel with small sails may exceed in speed a similar vessel with larger sails, or that one ship may outstrip another with a light wind, yet be overhauled and passed by her, under a heavier breeze. In fact, no artisan can apply a greater extent of physical science to useful purpose than the navigator in advising with the ship-builder, the stevedore, and the sail-maker, and in commanding his helmsman, and his mates. If you bear in mind that the resistance of a fluid

by its inertia, acts as if the whole force were acting at the centre of resistance or percussion;—that the hydrostatic pressure acts directly as the depth;—that projectile force and gravity act as if concentrated in the centre of gravity, and the buoyant force impressed upon floating bodies acts as if concentrated at their centres of buoyancy, you will perceive how completely questions of fluid resistance are regulated by the laws of the pressure and impact of solids, and will have no more difficulty in understanding the effect of a stream in turning a water-wheel, the wind in driving a sail, or a sail in driving a ship, than in calculating the motion of a pendulum, the resolution of the force exercised by one billiard-ball upon another, the overturning of a carriage on the hill-side, or any question involving the laws of inertia, the inclined plane, and the lever; except so far as it is more difficult to understand the effects of a great many little bodies (particles) than those of a single large body. Most of these questions, indeed, may be determined mainly by the resolution of forces and the law of the lever, if we neglect the effects of fluid cohesion and friction, which compel us generally to correct our theory by experiment.

580. *Of Waves.*—When a pebble is thrown into a pond, it not only depresses the column of water upon which it strikes, but thrusts aside part of the water which it displaces. The inertia of the water beyond the immediate influence of the blow, prevents the particles from moving freely in a lateral direction, to allow room for the pebble, and they therefore become piled up on all sides, by the action of the two opposing forces, and are compelled to assume the form of a

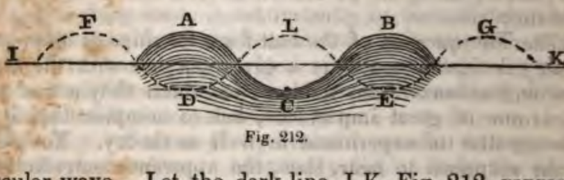

Fig. 212.

circular wave. Let the dark line, I K, Fig. 212, represent a view in section of a fluid surface beneath which a pebble has just disappeared at C. The pit formed at this point then represents the depression of the column on which the pebble fell, and the round elevations, A and B, are views in section of the circular wave thrust aside by it; neither of which, in the first instance, changes perceptibly the general level of

he water marked by the horizontal parts of the dark line, I K. Now, it is evident, from the laws of fluid pressure, that every particle in the wave, A B, which is above the level, must fall by gravity when the disturbing cause ceases to act, and that every particle at the surface of the little pit, C, must rise by the hydrostatic pressure of the fluid around it. Let the black dots at A and C represent two particles; one in the wave, the other in the pit. By the laws of gravity, the particle A will fall with increasing velocity till it reaches the general level; but, by the laws of momentum, it cannot stop there: it must continue to fall with a retarded velocity, until its acquired momentum is lost in overcoming the upward pressure of the increasing column of water above it; and this is only accomplished (friction and atmospheric resistance excepted) when it has fallen as deep below the surface as it was previously raised above it. For precisely similar reasons, the particle C must rise to an elevation equal to its previous depression. Thus each particle in a wave has a tendency to vibrate like a distinct pendulum; and hence, in a few moments, the depression becomes an elevation, and the elevation is changed into a depression, as represented by the dotted line in the figure at L, D and E. It is evident that this vibration would continue without end, were it not that atmospheric resistance and other causes soon destroy the vibratory motion, and bring the water to rest.

581. The motion of the water in waves, when undisturbed by other causes than the momentary forces producing them, is therefore almost exclusively an upright, and not a progressive motion. Why, then, do waves, raised by a pebble, appear to roll outwards, in concentric and spreading circles, until they cease to rise perceptibly above the surface in consequence of the increase in width and diminution in height caused by friction and atmospheric resistance? This difficulty will at once disappear when you consider that the particles immediately around the pebble or any other depressing force are first thrown up above the general level, the more distant columns of molecules being elevated successively, until the whole of the first wave is formed. But the column nearest the centre, which is the first to rise, must also be the first to sink, and no column can sink without some other corresponding column rising to make room for it. Therefore, all the particles on the side of the wave next its origin must be subsiding at all times, while those on the opposite side must be constantly moving upward. Moreover, while the pit C is being filled up, the *figure* of the wave, A B, is sink-

ing, and its *matter* exercising pressure upon the surrounding water equally in all directions. Therefore; as column after column of particles subsides on the surface next the pebble, a similar number of columns must rise from the general level towards G and F, under the action of this pressure, and thus the *figure* of the wave rolls on to F G, followed by the circular groove, D E, created in the same manner by the descending columns of the same wave in rear and the rising columns of the new central wave, L. The figure, I say, rolls onward, but the matter of the wave simply vibrates upward and downward, without any onward movement. You can now understand why two waves meeting each other may ride over each other without interfering, and continue their several routs. Throw a handful of pebbles into a quiet lake, and you will produce a multitude of waves in concentric circles, moving off from many centres, and intermingling in seeming confusion but real order. You are now also able to comprehend the reason why heavy waves roll towards the shore in calms, or even in direct opposition to the wind; and why a high swell often informs the mariner of the occurrence of a gale at a distance of a hundred miles, while, perhaps, his vessel is rolling her masts out upon the surface of a heaving ocean, glassy in smoothness, and unruffled by a breath of air.

582. When a liquid is already in a state of undulation, and another force gives rise to a new local depression or elevation, the newly-formed waves may be said to regard the actual surface at each moment as if it were the permanent form of the surface; and they proceed in the same order over the pre-existing waves and furrows as if the liquid were at rest. Hence one wave may become piled on another, and one furrow may be grooved out at the bottom of another, so as to increase the height and depth of the apparent waves. Thus, when two equal waves meet in such a manner that the summit of one is distant from the other by exactly the length of either wave, measured from the bottom of one furrow or *trough of the sea* to the bottom of the next, the height of the swell is doubled at the moment of their coincidence.

583. But, on the other hand, though the matter contained in waves is impermeable, the forms or figures which we call waves are not material, being only composed of variable spaces, defined for the moment only, by matter in a state of motion; and they are therefore perfectly permeable, as all *spaces* are permeable. Hence, if one wave meet another in

such a manner as to retard the motion of the moving columns of liquid, the height and depth of the waves will be necessarily diminished, as if one wave *rolled into* another instead of *rolling over* it. Thus; if two equal waves meet in such a manner that the summit of one wave, if continued, would correspond exactly with the trough of the other, *they must produce smoothness of surface;* because the columns of particles at the place of meeting are urged upward by the elevation of one of the approaching waves, and downwards by the depression of the other, at the same moment of time; and these equal and opposite forces must necessarily produce a state of relative rest.

584. Between the two foregoing effects of the meeting of waves, every variety of intermediate effect may be produced. Hence, a fresh gale not unfrequently smooths a previously rough sea, for a time, until a new swell is occasioned by its continuance.

585. The tendency of waves to flow outward from a centre, is always the same, though the form of the depression which gives rise to them must determine great varieties in the mode of its display. The most common cause of their production is the friction and unequal action of winds or currents of air upon a watery surface. The first puff of wind upon a fluid raises a succession of ridges, and the inertia of the particles in each ridge produces a resistance to the breeze which shields one side of the adjoining lateral hollow from its effects, while it allows its whole pressure to act on the opposite side. Thus, the inequality once produced, the same cause continually increases the height and width of the "swells," until the nature of the fluid precludes their farther growth. These ridges are necessarily long and narrow, and appear to chase each other in straight lines; but the influence of any obstacle will at once display the incorrectness of this appearance; which results simply from the length and parallelism of the ripple rubbed up by the wind.

586. If waves rolling in from the sea strike upon a pier or wharf, those portions which meet the obstacle are reflected, and upon the farther side of the pier the water remains smooth, forming a safe harbour for shipping; but those portions of the swell which pass the extremities of the obstacle continue their course unchecked, and, on passing beyond it, they gradually spread themselves out in concentric arcs of circles, having the corner of the pier or wharf for a centre. Thus, by encroaching continually upon the smooth space as they advance, they render the water again rough at some dis-

tance from the pier, and contract the dimensions of the harbour.

587. When parallel waves strike a perpendicular wall directly, they are reflected directly; producing one form of what is termed *a chopping sea.* If they strike obliquely, the part which first touches the obstacle is first reflected, and as succeeding portions of the figure of each wave rebound from the surface, this figure rolls off at an angle equal to the angle of incidence, producing what is called *a cross swell or sea.* For like reasons, when circular waves meet such an obstacle, each wave is returned in the form of a reverted arc of a circle, and the retreating swell seems to spread from a centre as far beyond the obstacle as its real source is distant on the side towards which it moves. Thus you perceive that these mere forms of space, because they are determined by the moving matter which describes them, are governed by the same laws of reflection which regulate the motion of elastic solids impinging upon hard substances.

588. The nature of water renders it incapable of rising into simple waves with summits more than ten feet above the general level of the fluid; which, added to the depth of the corresponding furrows, gives twenty feet for the extreme height of the largest simple wave: but, as the matter of every wave is governed by the laws of fluid pressure that regulate water at rest (582), a ripple produced by any cause upon the surface of a wave gives rise to a secondary series of ridges surmounted upon the first, and continuing its course over ridge and furrow. A third or a fourth series may be thus superadded, until the water is piled to a considerable height; but the stories, so often told by seamen, of "billows mountain high," are the result of mere optical deception, resulting from the rocking or pitching of the vessel, as she plunges or *heels over* towards the trough of the sea. This deception is similar to that which causes a hill to appear magnified in height and steepness when viewed from the summit of a neighbouring hill of nearly equal height.

589. Though waves are thus limited in height, they are unlimited in bulk. The greater the extent of surface on which they play,—the longer the continuance and the more general the action of the cause producing them—the greater will be their bulk. In narrow seas,—such as the great lakes of America, the Black, Caspian, Red, and Mediterranean seas, and the North Atlantic ocean—where winds are variable and the sheet of water moderate, the waves are often high and furious, but never *very* broad. They are therefore more

dangerous, particularly when *cross* or chopping, because of the sudden motions to which they subject a vessel. But in the Southern ocean, north of the icy regions and south of the Cape of Good Hope, where the wind blows almost perpetually from the west, and there is but little land to oppose and change the direction of a billow until it circumscribes the earth and renews its race, the waves are often more than a mile in width.

590. Sir Isaac Newton proved that if we consider the measure of the surface of the water from the summit of one ridge to the summit of the next as the breadth of a wave, and cause a pendulum to be formed equal in length to this measurement, the water will fall and rise again, and therefore the wave will advance through a distance equal to the length of its base, during each vibration of this pendulum.

591. Hitherto we have considered the action of waves when passing over deep water and uninfluenced by any other forces than those which cause the continuance of their vibration: we must now briefly notice certain effects of winds, currents, shoals, and coasts, upon their form and elevation.

592. When a general current is running in the same direction with a wave, in an open sea, the matter composing the ridge is carried along with it, while the perpendicular movement of the columns of particles is not altered. The wave, therefore, advances more rapidly in space, while it preserves the same rate of progress relatively to the moving water. If the current be adverse, the wave is retarded in the same manner. But if the wind be blowing at the same time, these effects are modified. When wind and current have the same direction, the latter, by carrying the wave more rapidly forward, diminishes the effect of the former; but when they are in opposition to each other, this effect is proportionally increased.

593. When waves in a channel suddenly meet a smoother current, coming from the water which is not in a state of vibration, this water sweeps into the figure of the approaching billows, and by its inertia disturbs the upward motion of the columns in front of the waves, rendering their acclivity more abrupt. If the current be rapid, it actually trips up the waves, so as to cause their summits to curl over and fall forward in regular breakers. The contest between such a current and a series of billows urged onward by the wind is often tremendous, and exceedingly dangerous to the navigator; but the most magnificent display of this action is seen in very rapid and large navigable rivers, in situations where the rise

and fall of the tides are remarkably great. The water rushing in from the sea, on the commencement of the flood tide, meets the stream descending from the land with powerful momentum, and becomes piled into an almost perpendicular wall, many feet in height, over which the still rising waters from the ocean pour down, as in a cataract, forming a continuous breaker across the river, which rushes up into the country, sometimes with almost the speed of a race-horse, frequently wrecking vessels and destroying life. This singular appearance is called a *bore*.

594. As it is the relative, and not the absolute motions of wind, wave, and stream, that regulate their several effects, it is evident that a sub-aqueous current at sea, opposing the wind and waves, or, which is nearly the same in its effects, a superficial current running with wind and wave over still water beneath, must produce a shortening of the front of each billow, and if rapid, a more or less complete tripping of the water, like that already described. The force of the wind being always greatest upon the subsiding declivity of a wave, tends to accelerate its fall; but the inertia of the water on the side which is becalmed resists this forward motion: hence, the retreating side becomes flattened, while the opposite side is rendered more bold, and thus the waves increase in height faster than they can in breadth, becoming more precipitous in front. A superficial current is always generated by the friction of the wind, and increased by its impinging force upon the elevated ridges. The weight of each ridge, at its base, renders it too heavy to yield perceptibly to the force of the wind:—not so the summits: these being lighter, are urged on more rapidly until they may lean over forward, and "comb," or fall and "break" in "white-caps."

595. Very heavy and sudden blasts of wind "knock down the swell," by blowing off the tops of the billows, and sometimes reduce a rough sea to a smooth sheet of water, covered with deep foam and spray, until, after some time, waves are formed so vast in width that their rate of speed bears some proportion to that of the gale, and the gentleness of their curvature preserves their tops. In all severe "blows," the lesser waves are tossed into foam, stretching far away, in long, dirty, white lines, to leeward, over the larger billows.

596. When waves advance from deep, into gradually shoaler water, the bottom necessarily acts as an inclined plane upon the water resting on it. The agitation produced by the waves is known to become trifling at a short distance below the surface; and some have fixed its limit at

hirty feet. This is undoubtedly an error; but we have reason to believe that

"——— the blue depth of waters
Where the waves have no strife,"

extends to within a distance of a few fathoms from the atmosphere. Now, if the bottom rise to within less than this distance, its reaction must modify the ascent and descent of the columns of particles forming a wave. The descending columns are retarded in their perpendicular motion, and the ascending columns in front are thus subjected for a longer time to their hydrostatic pressure; they must therefore rise higher: thus the ridge becomes more elevated, in relation to the general surface, while the reaction of the bottom prevents the corresponding depressions from subsiding so low, and the wave—a mere figure—is made to ascend the inclined plane, while the water is piled up towards the shoal by each succeeding wave. During the reflux, the water thus elevated, overbalancing the hydrostatic pressure of the ocean, lake, or river, seeks to regain the general level by forming a counter-current. It cannot do so on the surface, because this would require that it should ascend the approaching waves in opposition to gravity: it therefore steals off beneath, along the declining bottom, and thus retards and renders more abrupt the anterior surface of each billow, in the same manner as a counter-current. The water being thus continually urged upward on the surface by the waves, and escaping beneath in a continued stream called an "*under-tow*," it is evident that the matter, as well as the figure of the waves, must acquire a real motion onward towards the shoaler water; until the two opposing currents materially modify the form of the billows, and they become what are termed "ground-swells," which often cause the wreck of vessels by urging them upon neighbouring shoals. The ground-swell produces a peculiar motion familiar to mariners; and whenever it is perceived, the lead is cast, to ascertain the depth of water, though no shoal may have been known to exist in the place where it occurs.

597. If the inclined bottom ascend above the ocean level, and form a coast, the strength of the contending currents continually increases as the waves approach the shore, and are lifted more and more above the sea level; while the retarding effect of the under-tow, acting most powerfully upon the most advanced portion of each billow, ranges them more and more nearly into parallel lines, forming what are termed

moving body loses none of its energy. It therefore requires more than the square of the force in action to double the velocity of a boat, and this law soon limits the increase of speed with which such machinery can be propelled by art, by bringing the required force to a point which the material of the machinery will not endure without being crushed.

574. Bodies may be made to move so rapidly through water as to exceed the speed with which the particles can follow or close in laterally behind them. There is, then, of course, a vacuum formed in their rear; and they are compelled to conquer not only the inertia of the liquid before them, but, in addition to this, the entire hydrostatic pressure of the column of the liquid in which they are immersed, added, in most instances, to the pressure of the atmosphere resting upon it.

575. This increased resistance from hydrostatic pressure is not confined to bodies moving in a liquid: a cannon-ball experiences it in the air, and may pass so rapidly that even that light fluid fails to close up behind it in time to prevent the formation of a vacuum. It is found practically useless to discharge shot from cannon with a velocity greater than 1200 feet per second, because the velocity beyond that measure is almost immediately destroyed by the tremendous resistance of the air. Gases being compressible to a great extent, must be crowded before bodies in rapid motion, so as greatly to increase the resistance, in consequence of the elastic reaction of the air thus compressed between the moving body and the fluid which lies farther from it, and of which the reaction is not yet overcome. That the inertia of the particles, at some distance in advance, though acted upon by the pressure of the approaching mass, is not instantly or immediately overcome, is obvious from the fact, that the current produced by the motion is scarcely perceptible in front, but is very powerful behind the moving body. This latter rule applies to liquids called inelastic, as well as gases.

576. The influence of hydrostatic pressure in opposing the motion of bodies, is beautifully displayed by the effect of a steamboat passing rapidly along a narrow river. By studying the actual piling up of the water in front; the direction and causes of the waves that spread out from the bow and the waist of the boat, finally breaking upon either shore; the agitation of the water behind the stern, and the pursuing current in the wake, together with the course and influence of the great swells thrown up by the paddles, you may see developed a multitude of interesting problems in hydrostatics and hydraulics.

attraction are most obvious when it coincides in direction with that of the moon, producing the very high tides called *spring tides*, or when it opposes that of the moon, producing more moderate tides, called *neap tides*.

604. It strikes all young students with surprise that it should be high tide at the same time at the point of the ocean surface immediately under the moon, where her attraction is strongest, and at the point directly opposite this, where her attraction is weakest. The attempts made to explain this seemingly curious fact, in most elementary treatises, are very unsatisfactory. It is a problem too difficult for beginners, involving difficult calculations of attraction and the centrifugal forces of the earth and moon, and requires deep mathematical knowledge for its solution. I prefer the simple statement of the fact to an imperfect explanation, which could only give confused and imperfect ideas to mere beginners in the study.

605. Tides are not strictly waves, but they are affected in a similar manner by shoals, coasts, bays and rivers: hence the great varieties produced in their height and direction at different places; and as they act upon a vaster scale, these differences are proportionally more astonishing. In many parts of the Pacific ocean, the tides are scarcely perceptible; while in the Bay of Fundy, they rise from forty to sixty feet, producing terrific bores and breakers, and in one situation, on a narrow river, a temporary cataract actually falling up-stream, where, at low water, there is a beautiful cataract running in the usual direction towards the sea.

CHAPTER VI.

PNEUMATICS.

606. The general properties of solids and fluids have been already so completely illustrated that little remains for us to consider under the head of Pneumatics, except the apparently peculiar effects produced by the great elasticity of the airs and gases upon the motions and forces impressed upon these fluids; and as this remarkable elasticity is common to them all, though in different degrees, our attention will be almost exclusively confined to the peculiar dynamic properties of

moving body loses none of its energy. It therefore requires more than the square of the force in action to double the velocity of a boat, and this law soon limits the increase of speed with which such machinery can be propelled by art, by bringing the required force to a point which the material of the machinery will not endure without being crushed.

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576. The influence of hydrostatic pressure in opposing the motion of bodies, is beautifully displayed by the effect of a steamboat passing rapidly along a narrow river. By studying the actual piling up of the water in front; the direction and causes of the waves that spread out from the bow and the waist of the boat, finally breaking upon either shore; the agitation of the water behind the stern, and the pursuing current in the wake, together with the course and influence of the great swells thrown up by the paddles, you may see developed a multitude of interesting problems in hydrostatics and hydraulics.

577. The opposition offered to the motion of a body by a fluid depends much upon the form of the surface and the direction of its advance. If a flat body be moving directly against a fluid, the resistance from inertia is very great; and if obliquely, it is less in proportion to that obliquity; but it is unnecessary to enlarge upon this subject, for it is evidently regulated by the laws governing the action of solids upon inclined planes, modified by the peculiar conditions of the particles of different fluids. With those laws you are already acquainted; and the influence of these peculiar circumstances is much more readily determined by experiment and observation, than by reasoning and calculation.

578. The resistance from hydrostatic pressure is very much diminished when the moving body has a figure that facilitates the return of the particles in its rear after they have been divided in front. Ships and the most rapid fish are made rounding, though bold in front, to act with all the advantage of the wedge, scientifically curved in parting the water, while they are rendered more gradually sloping and taper behind, in order to allow the most ready return of the fluid to renew the hydrostatic pressure in the rear. If a ship were divided at her waist, and the front part furnished with a flat stern, it would sail with the utmost difficulty, leaving a deep trough in rear; and if a flat board be placed athwart the bows of a vessel, she advances no faster than she can move sideways, when properly constructed; because this board acts upon the water in the manner of a keel. A body with a concave surface is found to move through fluids with even greater difficulty than one that is perfectly flat: hence oars and paddle-wheels are sometimes made concave to increase resistance.

579. The question of the best form for ships or other machinery designed to answer a given purpose with the least possible resistance from fluids upon which they act or react, is one of great importance, but so complex that it is still a matter of experiment as well as theory. You will not be surprised to hear, then, the apparent contradictions that a vessel with small sails may exceed in speed a similar vessel with larger sails, or that one ship may outstrip another with a light wind, yet be overhauled and passed by her, under a heavier breeze. In fact, no artisan can apply a greater extent of physical science to useful purpose than the navigator in advising with the ship-builder, the stevedore, and the sail-maker, and in commanding his helmsman, and his mates. If you bear in mind that the resistance of a fluid

ing, and its *matter* exercising pressure upon the surrounding water equally in all directions. Therefore; as column after column of particles subsides on the surface next the pebble, a similar number of columns must rise from the general level towards G and F, under the action of this pressure, and thus the *figure* of the wave rolls on to F G, followed by the circular groove, D E, created in the same manner by the descending columns of the same wave in rear and the rising columns of the new central wave, L. The figure, I say, rolls onward, but the matter of the wave simply vibrates upward and downward, without any onward movement. You can now understand why two waves meeting each other may ride over each other without interfering, and continue their several routs. Throw a handful of pebbles into a quiet lake, and you will produce a multitude of waves in concentric circles, moving off from many centres, and intermingling in seeming confusion but real order. You are now also able to comprehend the reason why heavy waves roll towards the shore in calms, or even in direct opposition to the wind; and why a high swell often informs the mariner of the occurrence of a gale at a distance of a hundred miles, while, perhaps, his vessel is rolling her masts out upon the surface of a heaving ocean, glassy in smoothness, and unruffled by a breath of air.

582. When a liquid is already in a state of undulation, and another force gives rise to a new local depression or elevation, the newly-formed waves may be said to regard the actual surface at each moment as if it were the permanent form of the surface; and they proceed in the same order over the pre-existing waves and furrows as if the liquid were at rest. Hence one wave may become piled on another, and one furrow may be grooved out at the bottom of another, so as to increase the height and depth of the apparent waves. Thus, when two equal waves meet in such a manner that the summit of one is distant from the other by exactly the length of either wave, measured from the bottom of one furrow or *trough of the sea* to the bottom of the next, the height of the swell is doubled at the moment of their coincidence.

583. But, on the other hand, though the matter contained in waves is impermeable, the forms or figures which we call waves are not material, being only composed of variable spaces, defined for the moment only, by matter in a state of motion; and they are therefore perfectly permeable, as all spaces are permeable. Hence, if one wave meet another in

ch a manner as to retard the motion of the moving columns liquid, the height and depth of the waves will be necesrily diminished, as if one wave *rolled into* another instead *rolling over* it. Thus; if two equal waves meet in such manner that the summit of one wave, if continued, would orrespond exactly with the trough of the other, *they must roduce smoothness of surface;* because the columns of articles at the place of meeting are urged upward by the levation of one of the approaching waves, and downwards y the depression of the other, at the same moment of time; nd these equal and opposite forces must necessarily produce state of relative rest.

584. Between the two foregoing effects of the meeting of waves, every variety of intermediate effect may be produced. Hence, a fresh gale not unfrequently smooths a previously rough sea, for a time, until a new swell is occasioned by its continuance.

585. The tendency of waves to flow outward from a centre, is always the same, though the form of the depression which gives rise to them must determine great varieties in the mode of its display. The most common cause of their production is the friction and unequal action of winds or currents of air upon a watery surface. The first puff of wind upon a fluid raises a succession of ridges, and the inertia of the particles in each ridge produces a resistance to the breeze which shields one side of the adjoining lateral hollow from its effects, while it allows its whole pressure to act on the opposite side. Thus, the inequality once produced, the same cause continually increases the height and width of the "swells," until the nature of the fluid precludes their farther growth. These ridges are necessarily long and narrow, and appear to chase each other in straight lines; but the influence of any obstacle will at once display the incorrectness of this appearance; which results simply from the length and parallelism of the ripple rubbed up by the wind.

586. If waves rolling in from the sea strike upon a pier or wharf, those portions which meet the obstacle are reflected, and upon the farther side of the pier the water remains smooth, forming a safe harbour for shipping; but those portions of the swell which pass the extremities of the obstacle continue their course unchecked, and, on passing beyond it, they gradually spread themselves out in concentric arcs of circles, having the corner of the pier or wharf for a centre. Thus, by encroaching continually upon the smooth space as they advance, they render the water again rough at some dis-

tance from the pier, and contract the dimensions of the harbour.

587. When parallel waves strike a perpendicular wall directly, they are reflected directly; producing one form of what is termed *a chopping sea*. If they strike obliquely, the part which first touches the obstacle is first reflected, and as succeeding portions of the figure of each wave rebound from the surface, this figure rolls off at an angle equal to the angle of incidence, producing what is called *a cross swell or sea*. For like reasons, when circular waves meet such an obstacle, each wave is returned in the form of a reverted arc of a circle, and the retreating swell seems to spread from a centre as far beyond the obstacle as its real source is distant on the side towards which it moves. Thus you perceive that these mere forms of space, because they are determined by the moving matter which describes them, are governed by the same laws of reflection which regulate the motion of elastic solids impinging upon hard substances.

588. The nature of water renders it incapable of rising into simple waves with summits more than ten feet above the general level of the fluid; which, added to the depth of the corresponding furrows, gives twenty feet for the extreme height of the largest simple wave: but, as the matter of every wave is governed by the laws of fluid pressure that regulate water at rest (582), a ripple produced by any cause upon the surface of a wave gives rise to a secondary series of ridges surmounted upon the first, and continuing its course over ridge and furrow. A third or a fourth series may be thus superadded, until the water is piled to a considerable height; but the stories, so often told by seamen, of "billows mountain high," are the result of mere optical deception, resulting from the rocking or pitching of the vessel, as she plunges or *heels over* towards the trough of the sea. This deception is similar to that which causes a hill to appear magnified in height and steepness when viewed from the summit of a neighbouring hill of nearly equal height.

589. Though waves are thus limited in height, they are unlimited in bulk. The greater the extent of surface on which they play,—the longer the continuance and the more general the action of the cause producing them—the greater will be their bulk. In narrow seas,—such as the great lakes of America, the Black, Caspian, Red, and Mediterranean seas, and the North Atlantic ocean—where winds are variable and the sheet of water moderate, the waves are often high and furious, but never *very* broad. They are therefore more

dangerous, particularly when *cross* or chopping, because of the sudden motions to which they subject a vessel. But in the Southern ocean, north of the icy regions and south of the Cape of Good Hope, where the wind blows almost perpetually from the west, and there is but little land to oppose and change the direction of a billow until it circumscribes the earth and renews its race, the waves are often more than a mile in width.

590. Sir Isaac Newton proved that if we consider the measure of the surface of the water from the summit of one ridge to the summit of the next as the breadth of a wave, and cause a pendulum to be formed equal in length to this measurement, the water will fall and rise again, and therefore the wave will advance through a distance equal to the length of its base, during each vibration of this pendulum.

591. Hitherto we have considered the action of waves when passing over deep water and uninfluenced by any other forces than those which cause the continuance of their vibration: we must now briefly notice certain effects of winds, currents, shoals, and coasts, upon their form and elevation.

592. When a general current is running in the same direction with a wave, in an open sea, the matter composing the ridge is carried along with it, while the perpendicular movement of the columns of particles is not altered. The wave, therefore, advances more rapidly in space, while it preserves the same rate of progress relatively to the moving water. If the current be adverse, the wave is retarded in the same manner. But if the wind be blowing at the same time, these effects are modified. When wind and current have the same direction, the latter, by carrying the wave more rapidly forward, diminishes the effect of the former; but when they are in opposition to each other, this effect is proportionally increased.

593. When waves in a channel suddenly meet a smoother current, coming from the water which is not in a state of vibration, this water sweeps into the figure of the approaching billows, and by its inertia disturbs the upward motion of the columns in front of the waves, rendering their acclivity more abrupt. If the current be rapid, it actually trips up the waves, so as to cause their summits to curl over and fall forward in regular breakers. The contest between such a current and a series of billows urged onward by the wind is often tremendous, and exceedingly dangerous to the navigator; but the most magnificent display of this action is seen in very rapid and large navigable rivers, in situations where the rise

and fall of the tides are remarkably great. The water rushing in from the sea, on the commencement of the flood tide, meets the stream descending from the land with powerful momentum, and becomes piled into an almost perpendicular wall, many feet in height, over which the still rising waters from the ocean pour down, as in a cataract, forming a continuous breaker across the river, which rushes up into the country, sometimes with almost the speed of a race-horse, frequently wrecking vessels and destroying life. This singular appearance is called a *bore*.

594. As it is the relative, and not the absolute motions of wind, wave, and stream, that regulate their several effects, it is evident that a sub-aqueous current at sea, opposing the wind and waves, or, which is nearly the same in its effects, a superficial current running with wind and wave over still water beneath, must produce a shortening of the front of each billow, and if rapid, a more or less complete tripping of the water, like that already described. The force of the wind being always greatest upon the subsiding declivity of a wave, tends to accelerate its fall; but the inertia of the water on the side which is becalmed resists this forward motion: hence, the retreating side becomes flattened, while the opposite side is rendered more bold, and thus the waves increase in height faster than they can in breadth, becoming more precipitous in front. A superficial current is always generated by the friction of the wind, and increased by its impinging force upon the elevated ridges. The weight of each ridge, at its base, renders it too heavy to yield perceptibly to the force of the wind:—not so the summits: these being lighter, are urged on more rapidly until they may lean over forward, and "comb," or fall and "break" in "white-caps."

595. Very heavy and sudden blasts of wind "knock down the swell," by blowing off the tops of the billows, and sometimes reduce a rough sea to a smooth sheet of water, covered with deep foam and spray, until, after some time, waves are formed so vast in width that their rate of speed bears some proportion to that of the gale, and the gentleness of their curvature preserves their tops. In all severe "blows," the lesser waves are tossed into foam, stretching far away, in long, dirty, white lines, to leeward, over the larger billows.

596. When waves advance from deep, into gradually shoaler water, the bottom necessarily acts as an inclined plane upon the water resting on it. The agitation produced by the waves is known to become trifling at a short distance below the surface; and some have fixed its limit at

thirty feet. This is undoubtedly an error; but we have reason to believe that

> "——— the blue depth of waters
> Where the waves have no strife,"

extends to within a distance of a few fathoms from the atmosphere. Now, if the bottom rise to within less than this distance, its reaction must modify the ascent and descent of the columns of particles forming a wave. The descending columns are retarded in their perpendicular motion, and the ascending columns in front are thus subjected for a longer time to their hydrostatic pressure; they must therefore rise higher: thus the ridge becomes more elevated, in relation to the general surface, while the reaction of the bottom prevents the corresponding depressions from subsiding so low, and the wave—a mere figure—is made to ascend the inclined plane, while the water is piled up towards the shoal by each succeeding wave. During the reflux, the water thus elevated, overbalancing the hydrostatic pressure of the ocean, lake, or river, seeks to regain the general level by forming a counter-current. It cannot do so on the surface, because this would require that it should ascend the approaching waves in opposition to gravity: it therefore steals off beneath, along the declining bottom, and thus retards and renders more abrupt the anterior surface of each billow, in the same manner as a counter-current. The water being thus continually urged upward on the surface by the waves, and escaping beneath in a continued stream called an "*under-tow*," it is evident that the matter, as well as the figure of the waves, must acquire a real motion onward towards the shoaler water; until the two opposing currents materially modify the form of the billows, and they become what are termed "ground-swells," which often cause the wreck of vessels by urging them upon neighbouring shoals. The ground-swell produces a peculiar motion familiar to mariners; and whenever it is perceived, the lead is cast, to ascertain the depth of water, though no shoal may have been known to exist in the place where it occurs.

597. If the inclined bottom ascend above the ocean level, and form a coast, the strength of the contending currents continually increases as the waves approach the shore, and are lifted more and more above the sea level; while the retarding effect of the under-tow, acting most powerfully upon the most advanced portion of each billow, ranges them more and more nearly into parallel lines, forming what are termed

"rollers;" and these are rendered steeper and narrower in front, until they comb, topple over, and form those terrors of mariners called *the breakers*. The onward motion of the surface continually increases, and when a wave at length descends upon the coasts, it falls like a torrent upon the beach,—particularly if urged by the wind—and sweeps up far above the level of the summits of the highest waves. If it then meet a perpendicular or steep rocky ascent, it may be dashed in spray to an astonishing height. Solid rocks of great size are often broken or carried far inland by the force of breakers; and the spray of the ocean sometimes sweeps over lofty promontories, such as that of Nahant, depositing its salt upon the summits of buildings or blighting vegetation for many miles.

598. *Of Tides.*—The tides are great elevations of the ocean, resembling waves, in some respects, produced by the attraction of the moon, the sun, and other planetary bodies; those produced by the planets and more distant stars being, however, altogether imperceptible.

599. There are always two nearly similar tides co-existing on opposite sides of the earth, and the deepest depressions between them are found at the distance of ninety degrees from their points of greatest elevation.

600. If the earth were entirely covered with water, the points of highest tide would be found at all times a short distance eastward of those points on the earth's surface through which would pass a straight line drawn from the centre of the attracting body, and transfixing the earth through its centre also. It is evident that these points must apparently travel westward as rapidly as the body producing the elevation; and hence there would be two high and two low tides, in the course of about twenty-four hours.

601. The reason why high tides do not occur at any particular place exactly at the time when the attracting body is at the zenith or the nadir of that place, is simply this: the attraction continues to act for some time on the water, after this force has ceased to act with full vigour; and hence it continues to increase its previous effect for a time; nor is the upward momentum of the waters lost upon the instant that the attraction begins to decline.

602. The principal tides observed upon the ocean are caused by the attraction of the moon, and occur about three quarters of an hour later every day, because the moon reaches its daily highest elevation later by about that length of time.

603. The sun also occasions tides; but the effects of its

attraction are most obvious when it coincides in direction with that of the moon, producing the very high tides called *spring tides*, or when it opposes that of the moon, producing more moderate tides, called *neap tides*.

604. It strikes all young students with surprise that it should be high tide at the same time at the point of the ocean surface immediately under the moon, where her attraction is strongest, and at the point directly opposite this, where her attraction is weakest. The attempts made to explain this seemingly curious fact, in most elementary treatises, are very unsatisfactory. It is a problem too difficult for beginners, involving difficult calculations of attraction and the centrifugal forces of the earth and moon, and requires deep mathematical knowledge for its solution. I prefer the simple statement of the fact to an imperfect explanation, which could only give confused and imperfect ideas to mere beginners in the study.

605. Tides are not strictly waves, but they are affected in a similar manner by shoals, coasts, bays and rivers: hence the great varieties produced in their height and direction at different places; and as they act upon a vaster scale, these differences are proportionally more astonishing. In many parts of the Pacific ocean, the tides are scarcely perceptible; while in the Bay of Fundy, they rise from forty to sixty feet, producing terrific bores and breakers, and in one situation, on a narrow river, a temporary cataract actually falling up-stream, where, at low water, there is a beautiful cataract running in the usual direction towards the sea.

CHAPTER VI.

PNEUMATICS.

606. The general properties of solids and fluids have been already so completely illustrated that little remains for us to consider under the head of Pneumatics, except the apparently peculiar effects produced by the great elasticity of the airs and gases upon the motions and forces impressed upon these fluids; and as this remarkable elasticity is common to them all, though in different degrees, our attention will be almost exclusively confined to the peculiar dynamic properties of

atmospheric air and watery vapour, which furnish us with the most familiar examples of aeriform fluids of either class. To refresh the memory of the pupil, on the subject of the weight of air, and the equality of its pressure, I will occasionally describe a few experiments and phenomena connected with these subjects, as we proceed.

607. By means of a condensing-pump or syringe acting upon air like that attached to the Bramah press, air is forced into the copper ball attached to an air-gun. If a bag containing one cubic foot of air be emptied by this means into the ball, the weight of the latter will be increased one ounce and a quarter, while the same bulk of water weighs about 1000 ounces. Air, then, at the surface of the sea, and at a mean temperature and pressure, has about 1-769th part of the weight of water. Steam, on the contrary, when under the same circumstances, has little more than half the density of air, the relative densities at 212° of temperature being as 1 to 0.625. Water is composed of the matter of two gases, oxygen and hydrogen, of which the former is somewhat heavier than air, and the latter has about 1-13th part of the same weight. Air has been condensed under enormous force, until it outweighed an equal bulk of water, without assuming the liquid form, but the least increase of pressure instantly reduces a portion of steam at the temperature of 212° to water.

608. Under the common pressure of the atmosphere, air finds its way into the pores of all liquids, and nearly all solids, except the most dense among the metals. It can be pumped out from them by the air-pump, or forced into them in greater quantity by the condenser. Thus, when a cup of water is placed under the receiver of an air-pump, bubbles of air begin to rise through it, the moment the machine is put in motion.

609. The pressure of air, as well as that of water, is beautifully exemplified in the seemingly paradoxical toy called Hero's fountain, Fig. 213, in which water is made to ascend far above its level by means of hydrostatic pressure. A is a shallow, open basin, forming a cover for the close case or box, E. A tube, B, leads from the bottom of the basin, nearly to the bottom of another close box, C, and from the upper side of C, another tube, D, leads to the upper part of the box or chamber, E. From near the bottom of this chamber, a third tube, F, usually provided with a stop-cock, passes upward through the basin, A, and terminates by a narrow orifice at about the level of its edge. The tube, F, being closed, the

nber, E, is nearly filled with wa- and a sufficient quantity is also ed into the basin, A, to flow ugh B, so as to fill the lower nber, C, as high as the end of the . As the air in C and E has no as of escaping, while F is closed, little more water can enter C; more of the fluid being poured the basin, the tube, B, and the om of the basin become filled it, to a proper extent, and the is then ready for use. You per- e, at a glance, that the air in C is ected to the hydrostatic pressure he column of water in A and B; air being 769 times lighter than r, this pressure cannot be nearly aced by the column in C and D, ould be the case were these also l with water. But, by the law he equality of fluid action in all

Fig. 213.

ctions, the air in the upper part of E must press down- l upon the water in E, with nearly as much force as the mn in A and B exercises upon the air in C. This water, efore, tends to escape upward through F, with about as h force as the water in A and B endeavours to run down C. Turn the stop-cock then, and the water in A will through B into C, and pressing the confined air into E, air will react on the water in the same chamber, forcing rise in a jet from F to a height nearly equal to the h of the column in A and B. As the water of the jet back into the basin, it keeps up this action till all the r in E has been expelled by the air, and has flowed back ugh the basin and tube, B, into the chamber, C. By tituting a conducting-pipe for the jet, this contrivance been usefully applied to the raising of water for purposes rrigation and domestic use; for it is easy to renew the ess at any time by filling the chamber, E, and emptying chamber, C.

10. Thin square bottles are broken when exhausted of air, he hydrostatic pressure of the atmosphere without. A e of bladder tied over the neck of a wide-mouthed re- er, from which the air is then exhausted, is pressed upon owerfully as to be burst by the weight of the atmosphere.

These are common experiments performed before classes with the air-pump.

611. The barometer shows that the pressure of the atmosphere at the level of the sea, under ordinary circumstances, supports a column of mercury about 30 inches in height, though varying from 28 to 31 inches at different times. Mercury having a specific gravity of 13.57, it follows that this pressure would support a column of very nearly 34 feet of water. A column of mercury having a transverse section of one square inch, and a length of 30 inches, weighs 14.7 pounds, avoirdupois. This, then, is very nearly the pressure of the atmosphere upon every square inch of surface at the level of the sea, in ordinary times; and the pressure which the atmosphere exerts upon the whole earth is equal very nearly to the weight of an unbroken sea of mercury 30 inches deep, or a similar sea of water 34 feet deep, surrounding the entire earth. As a cubic foot of water weighs 1000 ounces, or $62\frac{1}{2}$ pounds, and mercury is 13.57 times heavier, it is easy to calculate very nearly what is the actual entire weight of the atmosphere, by deducting the solid content of the earth from a body of similar form with a radius 30 inches greater. By this means, the weight of the atmosphere is found to exceed 5000 billions of tons. If this great sea of air were of uniform density throughout, its height would be nearly five miles.

612. *Elasticity of Air.*—Several facts and experiments proving the elasticity and compressibility of air, have been given already in the preceding pages; but it is proper here to add some further illustrations. By means of a strong condensing-syringe, formed with a valve acting like those of a pump, air is forced in great quantities into a copper bottle or receiver, provided with a valve at its neck; and this vessel is screwed upon a gun-stock and barrel, in such a manner that the valve becomes connected with a peculiar trigger, which, when drawn, allows a portion of the air to escape into the barrel. This constitutes the air-gun; and so great is the elasticity of the confined air, that a bullet may be almost noiselessly shot forth from it with as much force and accuracy as by powder. An air-gun will throw from twelve to thirty balls in succession, before the charge requires renewal.

613. When a thin bottle, tightly corked, is placed under the receiver of an air-pump and the air exhausted from around it, the confined air within, being no longer counteracted by external atmospheric pressure, may expand with a

the water marked by the horizontal parts of the dark line, I K. Now, it is evident, from the laws of fluid pressure, that every particle in the wave, A B, which is above the level, must fall by gravity when the disturbing cause ceases to act, and that every particle at the surface of the little pit, C, must rise by the hydrostatic pressure of the fluid around it. Let the black dots at A and C represent two particles; one in the wave, the other in the pit. By the laws of gravity, the particle A will fall with increasing velocity till it reaches the general level; but, by the laws of momentum, it cannot stop there: it must continue to fall with a retarded velocity, until its acquired momentum is lost in overcoming the upward pressure of the increasing column of water above it; and this is only accomplished (friction and atmospheric resistance excepted) when it has fallen as deep below the surface as it was previously raised above it. For precisely similar reasons, the particle C must rise to an elevation equal to its previous depression. Thus each particle in a wave has a tendency to vibrate like a distinct pendulum: and hence, in a few moments, the depression becomes an elevation, and the elevation is changed into a depression, as represented by the dotted line in the figure at L, D and E. It is evident that this vibration would continue without end, were it not that atmospheric resistance and other causes soon destroy the vibratory motion, and bring the water to rest.

581. The motion of the water in waves, when undisturbed by other causes than the momentary forces producing them, is therefore almost exclusively an upright, and not a progressive motion. Why, then, do waves, raised by a pebble, appear to roll outwards, in concentric and spreading circles, until they cease to rise perceptibly above the surface in consequence of the increase in width and diminution in height caused by friction and atmospheric resistance? This difficulty will at once disappear when you consider that the particles immediately around the pebble or any other depressing force are first thrown up above the general level, the more distant columns of molecules being elevated successively, until the whole of the first wave is formed. But the column nearest the centre, which is the first to rise, must also be the first to sink, and no column can sink without some other corresponding column rising to make room for it. Therefore, all the particles on the side of the wave next its origin must be subsiding at all times, while those on the opposite side must be constantly moving upward. Moreover, while the pit C is being filled up, the *figure* of the wave, A B, is sink-

at what rate the air must expand in ascending from the level of the sea. The calculation would require, it is true, some knowledge of algebraical forms, which are excluded from the design of this work; and I must therefore confine myself to the mere statement of the result.

620. It has been proved, by barometrical observation, that the density of the air must be reduced to one-fourth, at a height of seven miles; and if we form an arithmetical series, beginning with seven, and having a common difference of seven, and a corresponding geometrical series, beginning with one-fourth, and having the same number for a constant multiplier, the members of the fractional series will represent the densities for each height in miles represented in the series of the whole numbers, that of air at the surface of the earth being represented by unity; Thus:

Height in miles,	7	14	21	28	35	42
Corresponding densities,	$\frac{1}{4}$	$\frac{1}{16}$	$\frac{1}{64}$	$\frac{1}{256}$	$\frac{1}{1024}$	$\frac{1}{4096}$

621. You can now readily comprehend why common lifting-pumps, which raise water twenty-four feet to the moveable bucket at the foot of a mountain, may fail to raise it twelve feet from a mine near its summit; and why the air becomes oppressive by its weight in the bottom of very deep caves or excavations, as it does in diving-bells, where the hydrostatic pressure of water is added to that of air.

622. By this same rule, the density of air at the height of 105 miles would be but the 1073741764th part as great as that observed at the surface of the earth. Air in this condition could not perceptibly interfere with the rays of light, propagate the waves of sound, retard appreciably the motion of a meteor, or make its existence known by any other action sufficiently considerable to be observed during the lifetime of one individual.

623. Though the law just laid down is sufficiently accurate for all practical purposes, it is easy to show that it is not *exactly* correct; for it is founded upon several suppositions which are not entirely true.

624. It can be shown that the repulsion of the particles of air under the influence of gravity, though undefined, and therefore said to be indefinite, is not absolutely without limit: but the series, in paragraph 620, can never cease by being continued, and therefore, according to the law there given, the expansion of air would never cease in consequence of its distance from the centre of attraction. Now, though we have reason to suspect that some fine ethereal medium actually occupies at least all that portion of space which is in-

uded in the solar system, we know that this medium can-
ɔt be air. The rules governing the action of gravity are so ell known that we could calculate the density of the atmo- ɔhere which must centre round each planet, if air existed verywhere; and as air produces effects upon the rays of ght which make its presence known wherever it exists in a ertain degree of density, we can determine by actual ob- ervation, whether it is present in its legitimate amount about he moon. We do not find it there, and hence our atmo- phere must be of moderate bounds, and should be regarded is a spheroidal *body*, enclosing the earth, bounded by the balance between the mutual repulsion of its particles and the attraction of gravitation which presses them together.

625. Our supposition that the force of gravity was uniform throughout the atmosphere, you already know to be erroneous; but though the weight of the air and its consequent pressure must diminish as we ascend, according to the known law of gravity, this fact merely hastens a little the rapidity of rarefaction, which the law above laid down would lead us to expect; and this is of scarce any importance in calculations bounded within the regions which can be traversed by man.

626. *Temperature of the Atmosphere.*—But pressure by the weight of the superincumbent air is by no means the only cause affecting its density. Heat and moisture, acting upon a part or the whole of the atmosphere, produce general or partial changes, and occasion many of the most curious phenomena in nature, on some of which we must now bestow a little attention.

627. Heat expands air or increases its elasticity, and cold contracts it or reduces its elasticity, according to the law already laid down (618). In using the barometer to compare the pressure of the air at different places,—as in ascertaining the height of mountains—we are obliged on this account to make allowance for the state of the thermometer, and to reduce our observations to a settled standard of temperature.

628. When any body is suddenly expanded, even by mechanical means, it becomes colder; or perhaps it would be more correct to say, that the space which it occupies becomes colder. If sensible caloric be really material, this is natural; for, if a given quantity of sensible caloric be diffused among the particles of a cubic foot of any substance, such as air, on expanding this substance to the extent of three cubic feet, the same amount of sensible caloric will be diffused through three times the space, and of course, must pro-

tance from the pier, and contract the dimensions of the harbour.

587. When parallel waves strike a perpendicular wall directly, they are reflected directly; producing one form of what is termed *a chopping sea*. If they strike obliquely, the part which first touches the obstacle is first reflected, and as succeeding portions of the figure of each wave rebound from the surface, this figure rolls off at an angle equal to the angle of incidence, producing what is called *a cross swell or sea*. For like reasons, when circular waves meet such an obstacle, each wave is returned in the form of a reverted arc of a circle, and the retreating swell seems to spread from a centre as far beyond the obstacle as its real source is distant on the side towards which it moves. Thus you perceive that these mere forms of space, because they are determined by the moving matter which describes them, are governed by the same laws of reflection which regulate the motion of elastic solids impinging upon hard substances.

588. The nature of water renders it incapable of rising into simple waves with summits more than ten feet above the general level of the fluid; which, added to the depth of the corresponding furrows, gives twenty feet for the extreme height of the largest simple wave: but, as the matter of every wave is governed by the laws of fluid pressure that regulate water at rest (582), a ripple produced by any cause upon the surface of a wave gives rise to a secondary series of ridges surmounted upon the first, and continuing its course over ridge and furrow. A third or a fourth series may be thus superadded, until the water is piled to a considerable height; but the stories, so often told by seamen, of "billows mountain high," are the result of mere optical deception, resulting from the rocking or pitching of the vessel, as she plunges or *heels over* towards the trough of the sea. This deception is similar to that which causes a hill to appear magnified in height and steepness when viewed from the summit of a neighbouring hill of nearly equal height.

589. Though waves are thus limited in height, they are unlimited in bulk. The greater the extent of surface on which they play,—the longer the continuance and the more general the action of the cause producing them—the greater will be their bulk. In narrow seas,—such as the great lakes of America, the Black, Caspian, Red, and Mediterranean seas, and the North Atlantic ocean—where winds are variable and the sheet of water moderate, the waves are often high and furious, but never *very* broad. They are therefore more

ceive why clouds generally render the days cooler, and the nights warmer. They diminish radiation.

632. For all these reasons, the general temperature of the atmosphere decreases rapidly as we rise above the level of the sea, and at a certain height, varying according to the latitude of the place, the cold reaches the intensity at which water freezes, even during the warmest portion of the year. Above this lies the region of eternal frost.

633. *Temperature of Climates and Mountains.*—The sun's rays fall almost perpendicularly upon the earth throughout the tropical region, more and more obliquely as the latitude increases through the temperate zones, and glance at a great angle, for a part of the year only, within the polar circles. The more direct the rays, the greater is the number falling upon any given space, and hence the greater is the amount of caloric received. This gives rise to the varieties of climate. You may see them imitated on mountain ranges, on the north sides of which the climate is much colder in our latitude, than on the south; because the sun is always to the south of us, and shines more directly on the side next him.

634. As the earth revolves round the sun in its annual course, its axis of daily revolution is placed obliquely to the plane of its orbit, always preserving very nearly the same direction. At midsummer, in the northern hemisphere, the north pole inclines towards him, and is illuminated, while at midwinter, it is the south pole that leans into his light. This occasions the succession of the seasons.

635. These changes necessarily affect the temperature of the atmosphere, and produce varieties in the limits of the frosty regions. Within the tropics, snow is unknown at the level of the sea; in the temperate latitudes, it occurs occasionally in winter, and very rarely in summer; while in the polar regions it is seldom absent for any great length of time. The limit of eternal frost is found, under the equator, at an elevation of a little less than three miles; in the latitude of Philadelphia, it is placed at a little more than 1.7 miles, and at the poles, it probably descends to the surface of the sea.

636. *Winds.*—As the sun heats the air unequally over different portions of the earth's surface, its influence continually disturbs the equilibrium of the aerial pressure, giving rise to the currents called winds. If the surface of the earth were smooth and level, these currents would be very regular, but as mountains and other irregularities react upon the air when in motion, their direction is rendered proverbially variable. Yet if we glance over the whole world in examining

this subject, we shall find evidences of a tendency to regularity, proving that even the winds are subject to mechanical laws. As the sun is always shining perpendicularly upon some part of the earth within the tropics, apparently coming northward during our summer, and retiring southward during our winter, the region in which his heat produces the greatest degree of rarefaction in the lower portion of the atmosphere, must pass in the same manner, northward and southward and back again with the seasons. This region is remarkable for its repeated calms and sudden gusts.

637. The air here perpetually expanded by the sun's rays, rises by its levity, and gives place to the denser fluid pressing upon it from the north and south. As it ascends, it expands until it diffuses or renders latent the caloric received from the sun; and being urged by new portions of heated air from below, it spreads itself towards the north and south, where, being less under the influence of the sun's rays, it becomes cooler, and therefore denser, and subsides to the earth, near the poles, to take the place of the heavy air continually flowing towards the tropical regions. By this action, the winds are chiefly produced, while both the mean temperature and the purity of the atmosphere are preserved; and were it not for the revolution of the earth on its axis, we should have a universal breeze blowing from the poles toward the tropics, near the earth, and from the tropics towards the poles above, these opposite currents maintaining a continual circulation.

638. *Trade Winds.*—But as the earth communicates its own revolving motion to the atmosphere, by friction, the direction of these great currents is materially modified. The general prevalence of calms and irregular gusts of wind immediately under the sun distinctly shows that the atmosphere at the surface is there revolving with the same rapidity as the earth, except when the expansion of the lower air by heat causes large quantities of it to rise suddenly upward, producing a rush of wind from all points toward that spot. If it were revolving more rapidly, the prevalent wind would evidently blow from the west,—that being the direction of the earth's motion—and if less rapidly, it would blow from the east. Now, as the current of heated air rises beneath the sun, it retains, at first, the velocity derived from the earth; but being obliged to move in a larger circle, it cannot quite keep pace with the earth, and therefore appears at first to have an easterly tendency as it flows off towards the poles. But as this upper air passes towards

the north and south, retaining much of its previous velocity, it is brought successively over parts of the earth which revolve in smaller circles, and soon begins to move more rapidly than the countries beneath it, thus producing an oblique wind in the upper air, which, instead of blowing directly towards the pole, tends more and more from the westward. When these currents reach the neighbourhood of the polar regions, so as to become denser, and descend, they reach a part of the earth revolving in a circle so small that their remaining velocity, brought from the tropics, causes a strong wind from the west, which, in the Southern Ocean, beyond the capes, where there is scarce any land to disturb the course of the current, blows pretty constantly, throughout the year. As the lower air of the polar regions moves towards the tropics, it gradually loses its increased velocity by friction, and the winds therefore become variable, though with a general tendency from the north, in the northern, and the south in the southern hemisphere. The two general currents, as they pass from the regions of variable winds towards the tropics, retain only the velocity of revolution acquired in those regions, while the countries over which they successively pass revolve with increasing rapidity: these currents, therefore, fail more and more to keep pace with the earth, until compelled to do so by its friction; hence the winds, which would otherwise be directly north or south, in the corresponding hemispheres, blow more and more from the eastward, until the currents approach the region immediately beneath the sun, where, coming together, and having gradually acquired by friction the same velocity of revolution with the earth on which they rest, they form that atmospheric region of calms and gusts, from which we started at the commencement of this description.

639. When any considerable column of air is rapidly expanded and prepared to rise, the pressure of the atmosphere in that region is necessarily diminished, and consequently the barometer must fall. This diminution of pressure, when it occasions gusts or storms, usually precedes the gale; and hence, a sudden and considerable fall of the barometer generally gives notice of the approach of a tempest. Upward currents, from this cause, are the most usual causes of storms; but the mere acquired velocity of a current descending suddenly in the polar regions may produce a gale; and such a current is often attended by a *rising* of the barometer. This latter phenomenon is said to be common in New Holland, from some unknown local cause.

640. *Monsoons and Prevalent Winds.*—The grand movements of the atmosphere, described above, enable us to account for all those prevalent winds which appear to be the result of general causes. Thus, the southern declension of the sun in winter, and his northern declension in summer,—which changes the position of the region of greatest aerial expansion—taken in connexion with the form of the coasts and mountains bordering upon the Indian Ocean, explains the cause of the monsoons or winds which blow six months in one direction and six months in the opposite direction, in the bay of Bengal and its neighbourhood. The same changes explain why the variable winds in the United States come more frequently from the northward in winter than in summer. The diversion of great currents by lofty and extensive ridges, explains many peculiar winds observed in other places, and the general uniformity of the course pursued by storms in particular neighbourhoods.

541. *Whirlwinds and Waterspouts.*—These changes of direction often produce conflicts between opposing currents, which act in such a manner as to create much more rapid and narrow currents towards the point in which the density of the surrounding atmosphere is least considerable; for, the momentum of currents of air must be governed by all the laws which regulate currents of water, modified only by the greater elasticity of the former fluid. In such conflicts, eddies and whirls are often produced; and as the same wind which is blowing near the earth very rarely extends to the upper air, these whirls assume the character of whirlwinds, often reaching to the clouds, which are frequently formed just where the lower and upper currents of the atmosphere meet. If, in this last case, the whirlwind passes over water, it may form a waterspout in the following manner. The centrifugal force of the whirling fluid causes a rarefaction of the air along the axis of the revolution, from the clouds to the water, which may almost reach a vacuum. The pressure of the atmosphere forces up the water into this space, from below, as into a pump, while the upper air with the clouds descend much more readily from above, until they often meet. The water, of course, can never rise in a mass to any great height, but the spray and foam are often tossed much higher by the force of the wind.

642. Extensive currents, moving in opposite directions and meeting directly, may occasion in air, as they do in water, an upward movement near the point of contact, because there may be no sufficient means of lateral escape

offered to the great masses of air, clashing with the vast force of their previously acquired momentum. This may pile up and condense the atmosphere, occasioning phenomena like to an atmospheric bore, and may account also for the fact that, during violent storms, the mercury in the barometer is usually much agitated, and towards the conclusion of the gale, sometimes rises high above its previous level, from the additional depth or density of the atmosphere at that place.

643. *Land and Sea-Breezes.*—The *partial* influence of the sun's heat produces effects similar to its general influence, but upon a smaller scale; as is beautifully displayed by the land and sea-breezes of large islands and the shores of continents. Earth radiates caloric more rapidly than water, while it arrests it more perfectly; consequently, the air over the land becomes more rapidly heated and expanded, during the day, than does that which rests upon the sea; consequently, the former rises while the sun is above the horizon, and the cooler air of the ocean rushes in to supply its place; thus forming the sea-breeze. On the contrary, during the night, the air over the land becomes cooler than that resting on the water, which fluid retains a temperature more uniform. After sunset, the quickly cooled and denser atmosphere of the land rushes out to sea to counterbalance the relatively lighter atmosphere of the ocean; and thus it forms the land-breeze. Whenever the heat of the sun takes more effect in any particular spot than on the neighbouring surface, there the same causes must constantly produce similar effects upon a still smaller scale. Thus, if one set of openings be made in the eaves, and another near the peak of a roof, the heat of the sun expands the air beneath the roof, and causes it to rush out at the peak, while cooler currents enter at the eaves. Thus you perceive that the ventilation of houses depends upon the same causes that produce the trade-winds, and can understand how a fire in the woods, or the discharges of powder in a sea-fight, may produce an upward current, followed, in many instances, by actual storms. When large fleets have been engaged in action, the vessels that have been crippled in the fight are often lost in the gale which almost always succeeds it. The general principles upon which these various effects depend apply equally to all fluids, and you will find daily occasion to apply them, if you will observe what passes around you.

644. *Moisture of the Atmosphere.*—It is found that when a vacuum is formed over the surface of any liquid,—water, for instance—particles of the liquid rise into the vacant

space in the form of invisible vapour, in consequence of the repulsion of the particles of the water by [illegible]. This process takes place at all temperatures known at the surface of the earth, but much more rapidly as the temperature increases from the lowest point to that at which the liquid boils; it is called evaporation. If there were no air about the earth, and no liquid but water on its surface, evaporation would continue from the water until it would create an atmosphere of vapour of sufficient weight to balance the expansive power of the caloric remaining in the water, which tends to drive off more particles. The height of the vapory atmosphere would therefore depend upon the temperature, and as this would vary under the action of the sun and other causes, as it now does, there would be a constant succession of condensation and evaporation produced by the changes of season, climate, currents, &c. Whenever a body of vapour passed into a cooler region, a portion of the atmosphere would fall in dew, mist, rain, snow, or hail; and whenever such a body, when clouded, passed into a warmer region, it would resume its transparency, while an additional bulk of water would be evaporated, to add to the quantity of the whole atmosphere, until the local pressure should be equal to the expansive force or elasticity of the liquid at the existing temperature in this region.

645. The expansive force of watery vapour, and consequently its density at any reasonable temperature, may be easily ascertained. If a bladder containing nothing but freezing water—being completely exhausted of air—be placed under the receiver of an air-pump, and the receiver be also exhausted, the bladder will become speedily filled with vapour capable of supporting a certain weight; and if the temperature of the water be increased to any given degree, the steam will be found capable of supporting a greater weight; thus we can measure the expansive force or elasticity of watery vapour through a considerable range of temperature. In order to observe the increase of elasticity at higher temperatures, we may employ a steam-boiler with a safety valve properly loaded. Experiments have shown the following results:

Table of Density or Elasticity of Watery Vapour.

Temperatures.	Elastic forces. Per square inch	Temperatures.	Elastic forces. Per square inch
32°	1⅛ oz.	180°	7½ lbs.
50	2¾ "	212	15 "
100	13 "	272	45 "
150	4 lbs.	290	60 "

646. Now, the tendency of water to assume the vapory form exists in equal force, whether the liquid be subjected to the pressure of air or not; and it is a curious fact that it actually displays itself to the same extent, though more gently and slowly, under the weight of the atmosphere, than in a vacuum. The molecules of evaporated water find their way between those of the air, just as the latter penetrate between the particles of solids, with a degree of difficulty proportional to the density of the matter to be penetrated.

647. M. Dalton appears to have shown that the two gases chiefly composing the atmosphere—oxygen and nitrogen—are not *combined* by the mutual attraction of their molecules, but simply *intermingled* in consequence of their several elasticities, and that all gases and the vapours are governed in this respect by the same laws; their particles being kept asunder simply by caloric.

648. It is only when the temperature increases the elasticity of water to an equality with that of the air pressing upon it, that it ever passes into vapour as rapidly as it can be supplied with latent caloric by surrounding bodies, or, in other words, begins to boil. It would then burst at once into vapour, with tremendous explosion, were it not for the time occupied in obtaining the necessary caloric to be rendered latent. At the surface of the sea, under an average of atmospheric pressure, this occurs at 212 degrees of temperature; both the expansive force of vapour and the pressure of the atmosphere being then equal to very nearly fifteen pounds on every square inch of surface. But at such a height as would reduce the mercury in the barometer fifteen inches, the atmospheric pressure would be but seven and a half pounds on the square inch; and, by consulting the table, you will perceive that water would there boil at a temperature of 180 degrees, could it obtain sufficient caloric suddenly; and, at 32 degrees, it would thus boil or explode under a pressure equal to one and a half ounces on the square inch; but, owing to the slowness with which it receives and renders latent the caloric communicated to it, it simply evaporates with great rapidity at low temperatures, even in vacuo; and the formation of bubbles of steam, which produce the phenomenon called boiling, does not take place in the exhausted receiver of a common air-pump, at a temperature much below 100 degrees. In a perfect vacuum, it is supposed that boiling would occur at 75 degrees. Ether, floating on water, boils spontaneously and so rapidly at ordinary temperatures, in a tolerably complete vacuum, that it may be made to freeze the water by absorbing its caloric and rendering it latent.

649. Evaporation goes on from the surface of ice, even at temperatures far below the freezing point; for, if you place a piece of this substance in the open air, in one scale of a balance, with a counterpoise in the other, even when the thermometer stands at zero, a few days will convince you that the ice has become obviously lighter, especially if the wind be blowing; for evaporation is more powerfully resisted by still air than by air in motion. In consequence of this latter fact, water may be cooled for drinking by placing it in a porous, unglazed vessel, or one covered by a wet cloth, and exposing the vessel to a strong current of dry air. If the cloth be kept wet with ether, and the vessel be small and thin, ice may be formed in this manner. The former process is commonly used, and the latter has been effected in the hottest climates.

650. If the atmosphere were quiescent, evaporation would soon fill the intervals of its particles with a quantity of vapour varying in every part with the *pressure*, which tends to increase the density of aerial fluids and the *temperature*, which, when increased or diminished, tends to expand or contract these fluids. This quantity would everywhere be the greatest in density which could be rendered invisible by evaporation under the existing pressure; and now, if caloric were extracted from any part of the atmosphere, when thus charged with moisture, the air and vapour would both contract, from having their elasticity diminished by the loss of the repulsive force between the particles; and consequently their density would be increased. But the density of the vapour being already as great as possible under the existing pressure, even with the previous temperature, a portion of it would necessarily become condensed into water or ice, according to the degree of coldness,—taking the form of cloud, mist, dew, rain, hail, or snow: and this condensation would continue until all the vapour underwent the change, were it not that in contracting and changing its form, it gives out a quantity of latent caloric which, by elevating the temperature of the remaining vapour as well as that of the air containing it, soon stops the process by reproducing a balance between the pressure and the repulsive force.

651. If, in a mixed atmosphere usually quiescent, an upward current were to occur, the vapour would expand and become colder, in the same manner as the air; for all gases and vapours expand equally, with similar additions of heat, because the antagonizing force of cohesive attraction is imperceptible in aeriform fluids, and their expansion is regu-

lated by the heat alone, not by the repulsion of the particles themselves. But the vapour cannot expand without rendering latent an additional portion of caloric, and this caloric it must obtain from itself, for it cannot obtain it from the expanding air, which requires for its own use all that it can supply. Now, if caloric be taken from vapour at any temperature, when that vapour is as dense as possible under the existing degree of pressure, at the moment, it is evident that it must become *more* dense than possible while it retains the vapory form. A portion must therefore return to the liquid or solid state, producing a cloud, fog, snow, hail, or rain, which would fall towards the earth; and this portion, by liberating part of its latent caloric, supplies the remaining vapour with that caloric which is required to maintain its proper elasticity under the diminished pressure of the higher region which it enters.

652. On the contrary, if, in such an atmosphere, a downward current were to occur, the vapour would be increased in density, and caloric would be pressed out of it, and would raise the temperature of the surrounding air, unless more vapour could be obtained from surrounding bodies by means of evaporation, to absorb or employ this caloric.

653. If, instead of an ascending or descending current, a polar or equatorial current were established, it is evident that the former would be continually acquiring more vapour by evaporation from the earth and sea, as it moved into warmer climates, while the latter would be continually depositing water in some of the forms already named, as it passed into colder regions, and that it would thus tend to moderate climates by means similar to those already described in a former chapter.

654. If you will bear in mind what has been already mentioned in relation to the great aerial currents and winds of our atmosphere, and recollect also that the air, everywhere mixed with vapour, sweeps that vapour along with it in all its changes of position, while air from which cold has expelled, by condensation, a portion of the vapour previously contained in it, cannot recover that loss except by the slow process of evaporation, you will comprehend that vapour must exist in excessive or deficient amount in every portion of the aerial ocean at different times, owing to the constant changes of pressure and temperature, the action of winds, and the variations of climate, the season, &c.

655. When the exhaustion of air from the receiver of an air-pump first commences, the remaining air therein becomes

misty by the condensation of vapour, owing to the coldness produced by its expansion; but, as the exhaustion is continued, this mist is again evaporated, in consequence of the decrease of the pressure, and the caloric shooting into the vacuum from surrounding bodies.

656. *Formation of Dew.*—Dew is produced by a deposition of water upon the surface of bodies so much colder than the air in contact with them as to reduce its temperature below the point at which the vapour in the air immediately adjoining them can wholly preserve the vaporous condition. A portion of this vapour, therefore, collects in drops of water upon the cold surfaces; and these coalescing, often form streams upon perpendicular bodies or inclined planes, as, on the outside of a pitcher containing ice in the heat of summer. The greater the relative density of the vapour with which the air is charged, the less is the degree of cold required to produce this appearance; and the particular degree of temperature at which it appears at any time is called *the dew-point.* When the air is highly charged with moisture, *the dew-point is therefore said to be low*, but when it contains much less vapour than its temperature would enable it to preserve in the vaporous state, *the dew-point is said to be high.* In warm and damp weather, we see dew running down the walls of buildings, and obscuring the window-panes and looking-glasses.

657. The atmosphere being transparent, opposes very little resistance to the radiation of caloric towards the open expanse of space; and the heat accumulated from the sun during the day, darts off with great facility, and with very little effect upon the air, during bright, clear nights, while the air itself,—a very bad conductor—parts with its caloric with much more difficulty. Consequently, those bodies which radiate heat most readily, become coldest during such nights; and nearly all bodies become colder than the air above them. But this air, when calm, is usually charged with its full amount of vapour during the day; and hence, when lying in contact with bodies cooled by radiation after sundown, it condenses, and deposites or *precipitates* a portion, in the form of water or dew, upon their surfaces. Green grass, flowers, and leaves, radiate much more readily than gravel or earth; and hence, the dew-drop on the rose, and the wet feet and bad colds of those "who love the moon." Wind promotes evaporation (649), and equalizes the temperature of the air near the earth, by mixing it with that which lies farther from the colder surfaces. Thus it diminishes the

quantity or prevents the formation of dew. Clouds, also, being opaque, arrest and throw back the radiating heat of the earth during the night; hence, on cloudy nights, dew is seldom seen.

658. *Formation of Clouds.*—However dry the air may be, it always contains considerable moisture near the surface of the earth. For this reason, if an upward current of seemingly dry air be formed by any cause, the air becoming expanded and chilled by rising, must at last reach a point at which a portion of its vapour will be condensed into mist, rain, snow, or hail, and will then descend towards the earth. If not previously evaporated by the hotter and drier air below, it will reach the earth, and appear around us in one or other of those forms; but if the heat and dryness of the lower air be great enough to cause it once more to assume the vapory form, it will cease to descend, and will disappear at a certain height, forming what we call a cloud.

659. The temperature of the air at the height at which this upward current begins to deposite moisture is the same as that at which dew begins to settle on the outside of a pitcher containing ice, when exposed to the same current, even at the surface of the earth: that is; *at the dew-point.* Now, the rate at which air becomes cooler by expansion and the rate at which it expands in rising being both capable of calculation, we have only to obtain the height of the dew-point at any time, and we can then determine at what height a cloud must begin to appear in the heated air which rises from the earth during the day, in consequence of the sun's heat, in the manner described under the head of winds. That the ordinary day-clouds of summer, the bases of which all rest at the same height, and also our common thunder-storms, are really occasioned by partial upward currents, is beautifully proved by the motions of kites flying at a great elevation, when such clouds pass over them. These are usually lifted up suddenly, to a considerable distance; and when, in experiments upon atmospheric electricity, a series of kites are attached to the same string, the uppermost is frequently whirled into an approaching cloud, before its successors are at all affected by the upward movement except by the jerking of the cord.

660. When an upward current of this kind rises far above the height where clouds begin to form in it, condensation of vapour continues, and the cloud is piled up, mass above mass, until, perhaps, it may enter the region of perpetual frost, when it will pass from the form of rain into that of snow

[illegible] according [illegible] the quantity deposited and the rapidity [illegible].

[illegible] brings the temperature down [illegible] that agitates and mixes the air [illegible] lies above this level, will form a cloud; [illegible] by many causes. The last [illegible] great fires and sea-fights that give rise [illegible] productive of heavy rain in many [illegible] almost perpetual cloud hangs over [illegible] being situated upon an island of [illegible] atmosphere much charged with va[illegible] a dew-point peculiarly low, while [illegible] of fires maintain a constant upward [illegible] Under favourable circumstances, rain [illegible] by fires or gunpowder, and this [illegible] purpose in some instances. Great [illegible] forests, or on the prairies, often extin[illegible] manner.

[illegible] currents of air, at temperatures corre[illegible] but containing very different [illegible] traverse the atmosphere, one above [illegible] directions: and as the dew-point is [illegible] between the temperature and the [illegible] constantly varying, these currents [illegible] of levels of different elevations, [illegible] a dew-point for the cur[illegible] it, very different from that exist[illegible] earth at the same place and time. [illegible] different strata of clouds so often seen [illegible] directions at the same moment.

[illegible] equator obtains a larger amount [illegible] proportion to its heat, than the [illegible] page 284), and as it con[illegible] to cooler regions, to the north and [illegible] greater amount of rain within the tropics than in any other part of the earth: and the quantity of rain, hail, and snow falling annually within the temperate zones greatly exceeds that observed in the polar regions. The rains within the tropics fall almost exclusively at the season when the sun is distant from the point of observation: so that "the rainy season" occurs at periods differing by six months on opposite sides of the equator.

664. *Measurement of Atmospheric Moisture.*—As vapour is lighter than air in the proportion of 0.625 to 1, and both are equally affected by changes of temperature, any mixture [illegible] two fluids must be lighter than an equal bulk of dry

air, at the same temperature. In certain calculations founded on the height of the barometer, allowances are made for the effect of moisture in varying the weight of air. For these and many other reasons, it is of great importance that we should be able to ascertain the amount of vapour present in the air at any time. By ascertaining the dew-point, and referring to a table of the elastic force of watery vapour calculated for every degree of temperature, we can arrive at this knowledge by calculation; but it is more convenient to employ instruments capable of indicating every change in the relative moisture of the air, without resorting to the troublesome process of determining the dew-point by experiment. Such instruments are called *hygrometers*, and they have been variously constructed. Anything that expands when exposed to moisture, and contracts on drying, may be made to act as a *hygrometer* or instrument for measuring atmospheric moisture, by being connected with machinery capable of measuring its changes of bulk. All animal and vegetable fibres undergo such alterations; and the human hair has been generally selected as practically the most convenient. The hygrometer of M. De Saussure, which has been the favourite instrument in Europe, consists of a hair, robbed of its oil by being boiled in water containing nearly a hundredth part of its weight of Glauber salts, and secured to a fixed point at one extremity, while the other extremity is wound around a small metallic cylinder revolving upon a pivot at one end, and passing at the other through a circular plate, like the face of a watch. This extremity of the cylinder carries an index or hand, traversing around a circular scale of equal parts engraved near the circumference of the index-plate. To keep the hair at all times properly stretched, a little weight of about three grains is suspended to a delicate silk fibre, encircling the cylinder in a direction opposite to that of the hair. The zero of the scale, or the point of greatest dryness, is found by marking the position of the index when the instrument is enclosed under a receiver made hot and dry, and placed on a hot plate of metal covered with potash, lime, or soda, which have very great power in absorbing moisture from the air: and the point of greatest dampness is obtained by placing the instrument under a receiver thoroughly wet within: the position of the index being carefully marked at each experiment. The interval between these points is divided into 100 equal parts or degrees, and the elongation of the hair by dampness or its shortening by dryness compels the index to measure on the scale the actual *hygrometric condition* of the air.

CHAPTER VII.

ACOUSTICS, OR THE SCIENCE OF SOUND.

665. If a particle of gunpowder be exploded in the atmosphere, much of the material of which it is composed is suddenly expanded into the gaseous or aerial condition, and a forcible impulse is communicated to the air around the newly-created gases. But momentum cannot be instantly communicated to the whole body of the surrounding atmosphere; and hence the nearest particles become compressed on all sides between the gases and the more remote air, which resists the expansion by its inertia. Thus, a condensed sphere of air is formed at some little distance from the point of explosion. Now, this compressed air being elastic, and not being fully balanced by the atmospheric pressure around and within it, instantly endeavours to expand again; and, while one portion of it springs back towards the centre, another portion is urged outwards towards the circumference of a larger sphere. Each of these portions becomes a cause of a new condensation; for the compressed air acts in a manner analogous to an explosive force, and gives rise to a new compression, both in the inward and outward direction. Thus the particles of air originally compressed by the powder are thrown into a state of vibration bearing some resemblance to that of the columns of water which constitute a wave in a liquid. It is evident also that the original impulse is continually propagated in all directions, from particle to particle, as it is propagated, in waves, from column to column; and hence the invisible *figure* of each condensed sphere advances continually through space, like the figure of a wave on the surface of a liquid, while the matter of each sphere merely vibrates backwards and forwards, without any permanent progression. Impulses of this kind are communicated from particle to particle, through the air, in a manner precisely similar to that in which impinging force is transmitted from ball to ball, in the experiments on elasticity performed with series of ivory spheres (303); and the rapidity of their progress will be proportional to the elasticity of the media in which they occur.

666. As there is absolute motion in the matter composing each pulse produced by the sudden agitation of air, the moving particles must produce all the effects of impinging bodies, when the pressure of the pulse reaches any obstacle; and as

the laws governing the impact of bodies have been explained in the first part of this work, you will have little difficulty in tracing their application to most of the phenomena of *acoustics, or the science which treats of the nature of sound.*

667. *Of the Ear.*—The ear is an apparatus delicately constructed to receive the impressions of the pulses produced by agitations of the air. An exquisitely sensitive nerve, called the auditory nerve, is expanded over the surface of a delicate membranous sac filled with a thin liquid, and enclosed in a curiously complicated system of cavities within the most solid portion of one of the principal bones of the head. A large canal of gristle or cartilage, situated beneath the skin or integuments, leads from the external ear down to this portion of bone enclosing the auditory nerve, and two small orifices through the bone allow the sac containing the nerve to come almost in contact with the lining of this canal; so that, at those points, thin membranes only intervene between the external air and the fluid surrounding the nerve. Somewhat within the middle of its course, the cartilaginous passage of the ear is divided into two apartments by a thin membranous partition, called the drum of the ear, which may be seen in many persons when we look, with a strong light, into the cavity of the external ear, which constitutes the door or porch of the outer apartment. The inner apartment also communicates with the external air, by means of a long membranous tube opening into the throat. Stretching from the centre of the drum to one of the little orifices in the bone enclosing the nerve, we find an exceedingly delicate arrangement of four minute bones, constituting a series of levers, provided with little muscles, by which the drum can be tightened or relaxed to a certain extent. Now, when air is thrown into sudden vibration, of the character described in paragraph 665, each vibration or *pulse*, as it is termed in acoustics, puts the drum of the ear into corresponding motion; and this motion being communicated from one small bone to another, along the system of levers, at last causes pressure upon the fluid in the sac containing the auditory nerve, and awakens the sensation of hearing, of which that nerve is the peculiar instrument.

668. We have chosen for our elementary example of a sonorous pulse, the effect of a sudden explosion in the air; but as this effect is entirely produced by elasticity, it is obvious that it must occur in all bodies that possess this property; and you have been told that no body is entirely divested of it. A sonorous pulse must therefore occur when-

ever any mechanical cause suddenly condenses the particles on which it acts. Place your ear close to one end of a log of dry wood, however long, and let a companion tap slightly with a pebble at the other:—you will then hear the blow through the wood, even when the distance is too great to allow you to hear it through the air. When an Indian is upon the watch for an enemy, he frequently lays his ear to the ground, and hears an approaching footstep through the earth long before it becomes audible to a person standing erect. If you strike two pebbles together when bathing, keeping your head beneath the surface for the moment, you hear the sound with painful distinctness; and if the blow be powerful and the pebbles large, the effect may be very dangerous to the organ of hearing. Thunder or a heavy cannonade sometimes causes the death of fish by the violence of the sonorous pulses communicated to the water.

669. As the particles in every pulse strike objects forcibly when the vibration reaches them, sonorous pulses themselves become the mechanical cause of analogous pulses in other bodies upon which they impinge: hence, thunder or a cannonade produce sound under water: the gnawing of a worm in the interior of a dry, solid plank, is heard at a considerable distance in the air, and a loud clap with the hands will make the glasses on the sideboard ring. But, it appears difficult for these pulses to pass from one medium to another, particularly in an oblique direction. If a bell be rung under water, it is heard distinctly, though feebly, by an ear placed directly over it, and the sound becomes rapidly more faint as the ear is removed from this position in any direction, until in a short time it is not heard at all. This is consistent with the laws that govern the resolution of forces; for the effect of the inertia of the air, in opposing the vibration of a particle in an oblique direction, is much more powerful than when it vibrates perpendicularly to the surface of contact.

670. To prove experimentally what has been already shown from reasoning, that sound is really produced by the vibrations of the particles of elastic matter, let a bell be kept ringing under the receiver of an air-pump, while the pump is in action. It will be found that the sound, heard loudly through the glass at first, becomes gradually fainter as the exhaustion proceeds. If this could be rendered complete, and if the bell had no connexion with the pump, it would not be heard at all; because there would be no matter left within the receiver to convey an audible impulse by its vibration. Through the thin air upon the tops of lofty mountains, the

loudest human voice sounds feebly, the discharge of a rifle is scarcely heard at a short distance, and even thunder speaks in a tone less dignified than that with which it awes the valley and the plain.

671. The ear is not necessary to the perception of sound, in all animals. Multitudes of beings exist without a trace of an ear or even an auditory nerve, yet display a sensibility to the motions produced by sound, in the most remarkable manner. The sea-anemone or animal-flower, for instance, contracts its beautiful arms and resembles a mere mass of animated leather, the instant that a footstep approaches the rock on which it is fixed. So, persons both deaf and blind distinguish the individuals of their family by the peculiar vibrations of the floor as they enter a room.

672. Like gravity, and all other physical effects emanating and diffusing themselves from a centre, the energy of the pulses of sound necessarily becomes diminished in proportion to the square of the distance from its origin.

673. *Reflection of Sound.*—When the particles set in motion by a pulse of sound impinge upon any obstacle, they not only awaken vibrations in that body, but fly back themselves, by virtue of their own elasticity, and in doing so, they react upon the air toward the side from which they originally came, in the same manner as the particles originally set in motion by the cause of the sound. Pulses, therefore, like waves and billiard-balls, rebound from opposing surfaces, making the angle of reflection always equal to the angle of incidence. If, then, a person call out in a loud voice, where hills, forests, or other obstacles obstruct the pulses of sound, they will be reflected in such a manner as to give the sound a totally different direction, producing what is termed an echo.

674. If the pulses fall perpendicularly upon the opposing surfaces, this echo will return to the ear of the speaker, as if he were mocked by some invisible spirit of the air. If two rocks, placed at a considerable distance from each other, present parallel surfaces, the sound of a pistol discharged between them will be tossed repeatedly from one side to the other, producing a fresh impression on the ear at every rebound until it dies away in consequence of the gradual weakening of the pulse by diffusion, the imperfection of elasticity, and other retarding causes. Such an echo is often heard in large rectangular halls, producing a musical note after every word spoken in the room, and confusing the voice of a speaker. If the hall be filled with people, and orna-

mented with furniture and drapery, this difficulty rarely occurs; for the multitude of pulses reflected from so many surfaces interfere with and destroy one another, so as to render more distinct the primary pulses occasioned by the voice. Two pulses of sound meeting each other may increase each other's effect, or destroy each other, producing silence as two waves sometimes produce smoothness (583). The impression of sound upon the ear is not lost in a moment, but continues for about the thirtieth part of a second of time. If a stick with fire at one extremity be slowly whirled in the hand, the eye follows the light, and perceives only the little coal that produces it; but, if the motion be more rapid, we see an entire luminous circle; because the impression made on the eye at the commencement of the motion is not lost until renewed by the return of the coal to the same position. So, when repeated pulses of sound reach the ear in slow succession, a series of distinct impressions are made upon the organs, which the mind can perceive and count; but when pulses follow each other more rapidly, the mind at last becomes incapable of dividing them, and a continuous sound is heard. If, in the latter case, the pulses follow each other in regular time, a musical note is produced; but if they be irregular, the sound is merely a noise; as when a cart is rattling over a stony street. The harshest simple sounds, such as the scratch of a pin on the teeth of a comb, become perfectly musical when produced in very rapid succession.

675. In small rectangular rooms, the first echo of a speaker's voice returns upon the ear so quickly as not to be distinguished from the primary sound; and thus the voice is actually increased in power without being materially confused. In such apartments, drapery and other inelastic surfaces diminish the power of the voice.

676. When a pulse of sound impinges obliquely upon a surface, it glances off in such a manner that the echo cannot return to the place where the sound originated, but will be heard in another direction determined by the angle of incidence. Let A, Fig. 214, represent the position of a sportsman, B and D those of two buildings in the distance, and C and E those of two observers. If a gun be

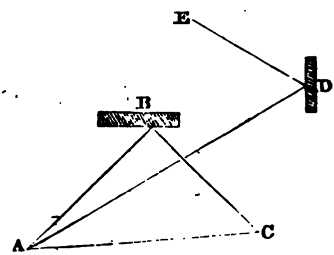

Fig. 214.

discharged by the sportsman, the direct sound will reach C in the direction A C; but, presently after, he will hear another discharge in the direction B C, which is the echo from B. On the contrary, E will be scarcely if at all able to hear the direct report; because he is placed behind the building B; but he will receive news of the discharge in the direction D E, in the form of an echo from D. As these reflections may take place from a great multitude of obstacles at very different distances, and may be repeated many times by those placed parallel to each other, you will understand the long rolling echo of a single musket discharged in an irregular mountain pass or an extensive cave, as also the reverberation of thunder,—a sound produced by a flash of lightning often stretching for miles in length, and reaching the ear successively from different distances, along the zig-zag course of the flash, each portion being reflected from cloud to cloud, and from these to the earth and back again.

677. Convex surfaces necessarily scatter an echo in all directions; because they reflect the sound always outwardly from the direct route of the primary pulse: regular concave surfaces, on the contrary, often concentrate sound; because they always reflect it towards some point within the sweep of the curve, if completed. Let A and B, Fig. 215, be two

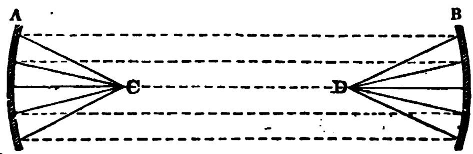

Fig. 215.

opposite spherical reflectors. It is a property of such reflecting surfaces, that if elastic bodies impinge upon them in parallel directions, as represented by the dotted lines of the figure, they will all be reflected very nearly to a fixed point, or *focus*, which is found half way between the surface of the reflector and the centre of the curvature; as at C and D in the figure. If a person standing at C were to speak, the pulses of the voice falling upon A, would be reflected to B in the direction marked by the parallel lines in the figure, and would be again reflected, and, as it were, condensed from B to the focus D, where the echo would be as distinct as the original voice to an immediate bystander at C, or even more so, while throughout the intermediate space the voice might be too feeble to be heard at all. Such surfaces frequently

present themselves in the walls of highly ornamented public buildings, and a conversation has been held by such means between two persons in opposite boxes of a theatre, it was inaudible to all but the parties themselves.

678. These remarks will explain the nature of whispering galleries, some of which were formerly constructed for the purpose of betraying to tyrannical rulers the concealed opinions of their subjects, and many are still to be found in public edifices erected without any such design. A cylindrical apartment is a whispering gallery, and the voice glances around it in such a manner that a whisper pronounced near the wall is distinctly heard by all persons standing near it in other parts of the room, though inaudible to others.

679. In large cylindrical apartments covered by domes the echoes are repeated in the most singular manner, and for a long time together, often commingled with new sounds generated by the vibrations produced by the pulses in the walls themselves, swelling and fading away alternately, and converting the harshest noise into musical tones. Few sounds can exceed in wild grandeur the music produced in the rotunda of the capitol at Washington, by the grating of the vane on the summit of the dome, or the creaking of the hinges of the many green doors by which it is entered. Heard during the intervals of the session of Congress, it seems to a poetical fancy like the wailing of spirits condemned for their unfaithfulness to their country in that great theatre of party strife.

680. If a person were placed in the centre of a hollow sphere, his voice would return upon him in full force from every part of the surface; and, were the sphere provided with an orifice, the sounds from within would be heard without, singularly modified by the size of the cavity. Any change in the position of the speaker or the form of the cavity would produce new modifications. The flattering slave of a tyrant of old constructed, to gratify his appetite for cruelty, a hollow brazen bull, in which to confine his victims. The inventor asserted that when a victim enclosed in this machine was slowly roasted by heating the statue, the bull would roar; and when, with some semblance of rude justice, he was himself submitted to this fiery ordeal, as the first test of his theory, he secured the triumph of his philosophical principles by the sacrifice of his life.

681. Sound may be confined in tubes, and conveyed by them to a great distance with little loss of force, because the

vibrations of the particles, instead of being propagated in all directions from a centre, are then compelled to take a simply longitudinal course, which may be either direct or winding. Tubes of metal for this purpose are now carried through the walls of many of our great hotels, from each floor or gallery to the general bar or office, in order to facilitate the conveyance of orders and messages.

682. By means of a tube passing from the mouth of a statue, through the wall and beneath the floor, to another apartment, the image may be made apparently to utter words; and, as it is not difficult so to construct an apartment that the sound of words spoken in a particular place therein shall be reflected into another room, either through a concealed tube or a hole in the partition, a mysterious conversation might be held with such a figure. In this manner, no doubt, many of the superstitions of the Egyptians and the early Greeks were imposed upon the people of an ignorant age, by their philosophical priesthood. Some pretended tricks of jugglery and ventriloquy in modern times are probably produced in a similar manner. A mischievous boy, at the top of a kitchen chimney, may easily alarm a superstitious cook by uttering complaints on behalf of a lobster just thrown alive into the boiling kettle below; for, a half-smothered voice in that situation will appear to issue from the fire-place, and the words may readily direct the attention of the hearer to the kettle alone—terror being not very nice in its discrimination.

683. Conical tubes, like the speaking-trumpet, allow the pulses of sound to expand a little, but give a direction to the impulse or vibration produced by the voice, more concentrated and powerful in the outward than in the lateral direction; as waves rolling through the interval between two piers, expand themselves but slowly and feebly in the circular direction. The successive pulses of the voice driven through the speaking-trumpet are continually reflected onward in an oblique direction, as the vibrating particles impinge upon the sides of the tube, giving much greater force to the sound in the direction of the cone, than if these pulses were free to propagate themselves on every side, as in the case of an explosion.

684. The common ear-trumpet for the deaf acts like a speaking-trumpet reversed. It concentrates all the sound received at its mouth, by continually reflecting the pulses *inward towards the* narrower part of the tube, where they *become proportionally* more intense.

685. *Of Musical Tone.*—The theory of acoustics has been more completely developed in consequence of the fondness of mankind for music, than from any other cause; and, fortunately, the study of musical tones enables us to arrive at just conclusions as to the nature and relations of sound more readily than by any other process.

686. As sound is produced by a pulse occasioned by a force or shock producing compression in the particles of any substance lying next the point where the force is applied, which condensation spreads or advances like a wave, until it reaches and affects the ear,—and, as continued sound depends upon a succession of pulses of this kind, following each other too quickly to be separated by the ear,—so, simple musical tone depends upon the production of *a regular succession* of such pulses striking the ear at equal intervals of time. To produce this regular succession of pulses, it is necessary that we should contrive to strike the air or other medium in which sound is to be produced, by means of some force that may be repeated at regular and short intervals. This may be effected in many ways, most of them dependent upon the production of vibration in elastic bodies. On such vibrations depend the tones of the human voice and all musical instruments; but their nature is most easily explained by examining the laws which govern the motions of elastic strings, of even weight and thickness, when stretched strongly between fixed points, and left at liberty to vibrate after being drawn for a moment from the straight position.

687. When a string attached to a fixed hook or button at one extremity is passed over a pulley or narrow strip of wood or metal called *a bridge*, placed at some distance from the first attachment, we may stretch it by means of any required weight, which will then be the measure of its *tension*. The distance between the fixed attachment and the bridge or pulley is considered as the *length* of the string, in our reasonings upon the subject.

688. Now, if a string, thus stretched, be drawn to one side and then left free, the stretching force and its own elasticity will cause it to return to its original position with considerable velocity; and its acquired momentum will then carry it to nearly the same distance in the opposite direction. Thus it will continue to vibrate like a pendulum, until brought to rest by the resistance of the atmosphere. It is not very difficult to prove mathematically that the time occupied in one double vibration of such a string is equal to the *length of* the string measured in inches multiplied by the

square root of the fraction whose numerator is *twice the weight of one inch of the string*, and its denominator *the weight which is equal to the force of tension multiplied by the number of inches through which a body falls by gravity in the first second of time;* which, at the surface of the earth, is 193. Mathematical formulæ are inadmissible in this work; and as it would require too much space to explain the subject in ordinary language, you must take the fact on trust at present, observing two consequences that follow from it: 1. The time of the vibration of any given string is an invariable quantity; and hence, as in the pendulum, the vibrations will be performed in equal times, whether their extent be great or little—whether the string be gently or forcibly struck: and, 2. When we know the weight, length, and tension of any string, we can readily calculate how many double vibrations it will perform in a second of time. This number may be found for any string by dividing the square root of 193 times the weight which equals the force of tension, by the length multiplied by twice the weight of an inch of string.

689. When a string vibrates less than 8 times per second, it produces no sound audible to man. Until the number increases beyond 16 per second, the vibrations continue visible to the eye, in strings of considerable length, and each vibration produces a pulse recognised by most ears as a succession of the same sounds repeated; but when the vibrations are increased to 32 or more per second, the separate pulses are no longer distinguishable, and a clear musical note is heard.

690. When the pulses arising from vibrations follow each other slowly, the tone or *pitch* of the note is said to be *low*, *grave*, or *bass;* but when the succession is more rapid, the pitch of the note becomes *higher*, *sharper*, or more *acute*. Tone or pitch, therefore, depends upon the number of vibrations or of the pulses produced in a given time; and in comparing the succession of pulses produced by the vibrations of different bodies, the second of time is usually taken as the standard.

691. If a number of strings, each of uniform weight throughout, be subjected to the same tension, their vibrations will vary inversely as their length; *i. e.* if such a string 32 inches long vibrates 32 times in a second, a similar string of half the length will have 64 vibrations, and one 4 inches in length will vibrate 256 times per second.

692. When strings have the same length and tension, their

number of vibrations varies inversely as the square roots of the weights of an inch of string. Thus; such a string, having four times the weight per inch of another, will vibrate just twice as fast.

693. The length and tension remaining the same, if the strings be all of equal specific gravity, the vibrations will vary inversely as their diameters. Therefore, such a string, if half as thick as another, will vibrate twice as fast.

694. When strings have the same length and the same weight per inch, their vibrations vary directly as the square root of their tension: Thus, if one such string be extended by a weight of 4 pounds, and another by a force of 16 pounds, the latter will vibrate twice as fast as the former.

695. If, in comparing the vibrations of different strings, you know the rate of any one of them, that of any other may be calculated by the rule of simple proportion very easily; for the number of vibrations varies as the square root of the weight which equals the force of tension, divided by the product of the length multiplied by the weight of an inch of string.

696. *The Octave—Musical Range.*—The human ear is most pleasantly impressed by pulses of sound that reach it at regular intervals. Even when the pulses occur at considerable intervals, as when several smiths are striking an anvil repeatedly with their hammers, regularity in the strokes destroys much of the harshness of the sound. It is this regularity that gives their chief charms to poetic measure and oratorical rhythm. If a single string be kept in vibration when stretched across two bridges, one of which is made to slide regularly towards the other, the fundamental tone or note of the full string will be found to rise regularly higher in pitch until the bridge reaches the middle of the string; when, the vibrations being exactly doubled in frequency, a note will be produced, so completely agreeing in its properties and effects with the fundamental note, that it is considered as the same note repeated. It is called the *octave*. If the bridge be carried forward until the string is reduced to one-fourth its length, the number of vibrations will be again doubled, and the note produced will therefore be a *second octave*, &c. All the range of musical sounds audible to the ear of man may be divided into *intervals* of musical pitch called *octaves;* and it is found that the entire range is included in about ten octaves.

697. *Concrete and Discrete Sounds—Speech, Song, and Recitative.*—In the last experiment, the sound rises from

one octave to another, without any break or interval of pitch. Such a sound is called *concrete;* and is rarely pleasant in music except as an occasional ornament, though in the human voice it produces all that variety of cadence which is so essential to expression and effect in speaking. It is heard, in fact, in the pronunciation of every syllable in speech, though usually limited to *intervals* of pitch, exceedingly short of that of the octave. In song and recitative, it is necessary to repress these sliding sounds, dwelling upon the concluding sound in the former style of music, and upon the initial or commencing sound in the latter style.

698. *Musical Notes.*—The organs of human speech and hearing are so organized that they utter and receive most readily sounds of different gravity or acuteness that follow each other at certain proportional intervals of pitch in preference to others; and even the mind is more pleasurably affected by such successions: hence, in all countries, the interval of the octave has been broken into smaller intervals, by certain points in the scale of pitch, called *notes,* not all of which are equal in extent. Notes are usually designated, with us, by letters; though not unfrequently, for convenience in teaching vocal music, certain syllables are substituted for them. Both modes are employed in the following table. These notes are called *discrete* sounds, because they are detached in pitch, and do no not slide into each other. There are seven such resting-places or steps in every interval of an octave:—Their names, their indicatory letters, the length of string necessary to produce each note,—that of the whole string producing the fundamental note being taken as 1,—and the relative number of vibrations for each note, also compared with unity, are displayed in the following table.

	Name.	Character.	Length of string.	No. of vibrations.
Fundamental or Key Note.	Ut or Do.	C	1	1
Second . .	Re	D	8-9	9-8
Third . . .	Mi	E	4-5	5-4
Fourth . .	Fa	F	3-4	3-4
Fifth . . .	Sol	G	2-3	3-2
Sixth . . .	La	A	3-5	5-3
Seventh . .	Si	B	8-15	15-8
Octave, or Key Note repeated.	Ut or Do	C	1-2	2-1

This order of notes and intervals being repeated in every octave, it is customary to say that there are but seven notes

in music, although the range of audible pitch extends to [illegible] octaves, of which some single musical instruments embrace six, and the human voice from one to three,—that of the female being generally an octave higher than that of the male. The upper and lower octaves are not heard by all persons, even among those who have a keen appreciation of music throughout the rest of the scale. Dr. Woollaston has shown that some of the larger animals hear and enjoy notes altogether too low for human ears: while others, of diminutive size, are affected by vibrations too rapid to awaken the attention of man.

699. *Musical Unison—Concord and Discord.*—When two or more sounds are heard at the same time, the effect will be more agreeable according to the frequency with which the vibrations correspond so as to produce their impression at the same moment. The greatest regularity of this kind is produced when any fundamental note is heard at the same time with one or more of its octaves: for, in this case, there is an exact correspondence in the pulses at every pulsation of the fundamental note. Next to vibrations producing the same note in the scale,—as when two strings of the same weight, length, and tension are vibrating together, in which case their sounds are said to be in *unison*,—those in which any note is heard in combination with its octave, appear most harmonious. Notes producing such agreements are called *concords*, while those of which the pulses rarely or never coincide are peculiarly disagreeable when heard in *concert*, and are called *discords*.

700. *Musical Chord.*—By examining the column in, the last table, which represents the relative number of vibrations producing each note, you will perceive a great difference in the number of coincidences in a given time between the pulses of the fundamental note and the several remaining notes of the octave: thus; in the *fifth*, or G, which pulsates three times for every two pulsations of the fundamental note, there will be harmony at every alternate beat of the latter. This, therefore, is the most perfect concord possible, except that of the octaves. If you examine the third, or E, in the same manner, you will find that it pulsates five times while the fundamental note pulsates four times; therefore, at every fourth pulsation, the sound of the notes of C, E, and G, and the octave, will coincide if heard together; while the fundamental note, in the meantime, will have concurred four times with the octave, and twice with the fifth. Any such combination of concordant notes is called a *chord*, and that

just given is the most simple and natural of all chords. The second and seventh notes are peculiarly discordant; because the coincidence of the pulses occurs only once for eight pulses of C and nine of D; while C must pulsate eight times and B fifteen times, in order to produce a coincidence.

701. You will observe that these notes are not positive, but merely relative points in the scale of concrete sounds; for we may take a string of any length, and consequently of any tone, for our fundamental note, and by placing it side by side with other strings of the relative lengths represented in the fourth column of the table, and of the same tension and weight per inch, we should produce notes in the order required for musical performance.

702. *Gamut, Diatonic, and Chromatic Scales.*—If the musical intervals of the written scale or *gamut* of discrete sounds, or, as it is usually termed, the *diatonic scale*, were all equal, we might begin a piece of written music upon any note, and by following the order of the notes by name, might perform it with perfect correctness. But these intervals are not equal; and hence, if music set to any given fundamental, or, as it is termed, *key-note*, be played upon an instrument tuned to any other note as a fundamental or key-note, we cannot produce, upon this instrument, the succession of natural intervals required to please the ear, merely by playing from the written notes in the same manner as if the music were expressly adapted to the instrument. Let us explain this more fully.

703. The relative whole numbers representing the number of vibrations corresponding to the seven notes and the octave composing the simple scale, are

Do	Re	Mi	Fa	Sol	La	Si	Do
C	D	E	F	G	A	B	C
24—	27—	30—	32—	36—	40—	45—	48

These numbers have various proportions to each other, and point out three classes of musical intervals in the scale:—1st, from C to D, from F to G, and from A to B; between each of which pairs of notes the vibrations of the lower to the higher note are proportionally the same, namely—as eight to nine:—2d, from D to E, and from G to A; between which pairs the vibrations are respectively as 9 to 10:—3d, from E to F, and from B to C; between which pairs the vibrations are as fifteen to sixteen. Tones of the first of these classes, being the longest, are called *major tones*, those of the second class *minor tones*, and those of the third, *semitones*. An octave is therefore composed of the follow-

ing succession of intervals:—1st, a major tone; 2d, a minor tone; 3d, a semitone; 4th, a major tone; 5th, a minor tone; 6th, a major tone; 7th, a semitone. The values of the letters affixed to the discrete notes in the table are, in nature, purely relative, and not absolute: if, then, we commence playing a piece of music beginning upon any pitch of sound whatever as a fundamental note, we find that as long as the intervals between our different notes correspond with the order just described—that is, as long as the interval from the fundamental to the second is a major tone, that from the second to the third, a minor tone, &c.—so long, and only so long, the succession of sounds will be agreeable to the ear: and, it is found that no piece of music produces satisfaction to the mind unless it terminates upon the fundamental note. Now, if a piece of music be written to correspond with any given pitch of sound as a key-note, the first interval above that note must be a major tone, the second a minor, and the third a semitone: but suppose we attempt to play this music on an instrument attuned to a key or pitch one major tone higher, as a fundamental or key-note; it is then evident that the first interval on the instrument, which corresponds with the second of the written music will be a major tone, while the latter will be a minor tone; and hence, the order of notes on the paper and that on the instrument cannot agree. In order, then, to make such an instrument *accord* with the written music, we must re-tune it, by varying the tension of the strings, so as to adapt them all to the natural succession of notes or intervals, in relation to the fundamental note of the written music; or, we must create new and intermediate tones on the instrument, in order to give at least an approximation to the natural order of intervals, adapted to any fundamental note. For this purpose it is customary, in the piano, to place additional strings in the major and minor interval of the scale, reducing the whole series to a system of half-notes, of which each is *a sharp* to the next lower, and *a flat* to the next higher note. This plan, though not positively accurate, is sufficiently near the truth to deceive the ear, and produce beautiful music. Such an arrangement of half-tones is called the *chromatic scale*. These explanations will assist you in understanding works upon practical music,—a branch which it is not our purpose to teach in the present essay.

704. It is this totally arbitrary assumption of any fundamental note, coupled with the absolute fixedness of the agree- succession of musical intervals, that constitutes the chief plexity of music; for, every key or fundamental note re-

quires its own arrangement of flats and sharps to secure the same order of intervals, which alone can render the consecutive sounds agreeable to the ear.

705. *Spontaneous Divisions of Vibrating Strings.*—If a bow be drawn slowly and regularly over the principal string of a violoncello, very near the bridge, the whole length of the string is thrown into a general vibration; but, at the same time, we often find it thrown spontaneously into a very different kind of vibration, which does not interfere with this general movement: thus, sometimes the opposite halves of the string will vibrate in opposite directions at the same time that the whole string is moving bodily from side to side. In this case, the half-strings beating with double frequency, must give rise to a note which is the octave of the fundamental note, and will be heard combined with it in perfect concord. Between these two vibrating halves, there is a spot which remains at rest, relatively to this part of the motion, though it partakes of the general swinging of the whole string; it is called *a knot*. Sometimes the string spontaneously divides in this manner, into three, four, or more portions, vibrating independently of the entire string, and separated by a suitable number of knots: and thus we may hear the fundamental note combined with the first or second octave, the fifth above the first octave, the third above the second octave, &c., commingling in beautiful concert from a single string, and varying with the number of knots by which it is divided. This combination is rendered still more rich by what is called the grave harmonic,—a sound often heard when two notes accord perfectly, formed by the impression made upon the ear by the coinciding pulses, and as deep in tone as the sound of a string vibrating once for each interval between these coincidences: thus, if a fundamental note and the fifth are sounding together,—the vibrations of the two strings will coincide at every second pulse of the former note, and this will produce upon the ear a sound like that of a string vibrating one-half as fast as that producing the fundamental note; this will be *the grave harmonic*, which, in the example just given, is of course one octave deeper than the fundamental note. When bells are chiming, most of you must have been surprised to hear tones in the air much deeper than the ordinary sound of either of the bells. These are grave harmonics, and add much to the effect of the chime. To make this subject clear to your mind, you may refer to Fig. 216, where A B represents an exaggerated picture of a string vibrating a given note,—C, for instance,—but spontaneously divided by a knot, E, at its

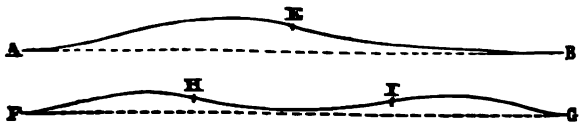

Fig. 216.

centre: and the two halves, A E, E B, vibrating independently. Here the whole string gives the fundamental note, C, and the halves each utter the octave of that note, because they vibrate twice as fast. F G represents an exaggerated picture of a string spontaneously divided by two knots at H and I. Here the whole string still utters the note C, but the parts F H, H I, and I G, are vibrating three times as fast, being only one-third as long. Now, by doubling all the numbers in the table on page 305, so as to adapt them to the octave next above, you will find that the fifth or G note of that octave has just three times as many pulses per second as the note C. The string, F G, will therefore sound the note C and the fifth above its octave in concord.

706. When a string is put in motion by a bow, a very skilful performer is able to cause secondary vibrations in it by dexterously and momentarily touching with his finger the spot where he wishes a knot to be formed; thus dividing the string at pleasure. In this manner, Paganini and others have been able to play regular harmonies upon a single string.

707. If three strings placed side by side be so tuned that the first string shall sound the fifth note below, and the third string the fifth note above that of the open middle string when touched by the bow, then, spontaneous vibrations are capable of producing with sufficient accuracy all the notes of music, though not in the same octave; thus showing that the divisions of the musical scale are founded in nature, and not in the mere arbitrary rules of art.

708. A series of sounds following the order of those which accord most perfectly—such as the fundamental note, its octave, the fifth and the third of the fundamental note—is more pleasing than that which includes discordant notes, such as the second and seventh. Such succession in music is called *melody*, and is one of the chief beauties of simple song; but the occasional and judicious introduction of a discord heightens the effect, by contrast; for invariable pleasure of any kind soon palls upon the appetite.

709. The combination of different notes heard at the same time and uniting in concord with each other, is called *har-*

mony; and this it is which gives zest to the rich performances in the higher walks of music, which require a cultivated taste for their appreciation and deep talent for their arrangement.

710. When a number of instruments are designed to act in concert, it is necessary that they should all be tuned to the same pitch, by selecting a suitable fundamental note upon some one of them, and regulating the musical intervals of all the others by that standard. This is often effected by the tuning-fork, a small instrument of steel, like a pair of sugar-tongs, with a handle, which, when struck upon any hard substance, vibrates and gives a note proportioned to its size. It is somewhat influenced by changes in the temperature of the atmosphere, which expands and contracts it like all other bodies, but not to an important extent.

711. *Wind-Instruments.*—In wind-instruments, the vibration is not lateral, as in a string, but longitudinal, and determined by the tube. It is found that whenever a rod of any elastic material, or a column of air enclosed in a tube, is thrown into the slowest possible longitudinal vibrations, the frequency of the pulses of sound, and, consequently, the note produced, varies inversely as the length of the tube or rod. If a rod be either fixed at both ends or free at both ends, it will vibrate twice as fast as when one end is fixed and the other free, and the same thing is true of the air in a tube. If we blow successively, and with the same force, into two tubes of the same length, one of them being closed at one extremity, like the barrel of a key, and the other open at both extremities, like a simple reed, the air in the latter will vibrate twice as fast and give a note an octave higher than that contained in the former tube. Thus; a trumpet, to be in unison with a flute, would require to be about half as long; because it is entirely closed by the mouth at one extremity, while the principal hole or *embouchure* of the flute causes it to act nearly as a tube open at both extremities. In this respect, the fife, flageolet, whistles, &c., resemble the flute. The reeds of the hautboy, clarionet, &c., vibrate in unison with the column of air within the tube, and assist in determining the succession of impulses by means of which the breath of the musician is admitted in order to produce the vibrations; and it is probable that the lips of the player perform a similar office in the trumpet.

712. In all wind-instruments furnished, like the flute and clarionet, *with keys* and finger-holes, the length of the tube *must be calculated* to the last hole that remains closed, or to

the extremity of the instrument when all are closed; for a lateral orifice in any part of the tube produces nearly as great an effect as the actual removal of the remainder of the instrument. Thus, we are able on the flute, when provided with suitable keys, to adapt our music to almost any fundamental note, by varying the length of the vibrating column by means of our fingers. A similar effect is produced in the trumpet, by the moveable pieces which are added or removed at pleasure. In the *cornet-a-piston*, the length of the tube is varied at pleasure, by a peculiar arrangement managed by means of a sliding-piece.

713. In wind-instruments, we usually possess the power of causing the column of vibrating air to divide itself into parts as the string is divided by knots (705); thus producing at will a series of three or more octaves, and sometimes other harmonics,—such as the *twelfth*, or *fifth* of the next octave above, the *seventeenth*, or *third* of the second octave above, &c.—by causing the column to vibrate in 2, 4, 6, 3, or 5 parts respectively. This power, combined with the keys and finger-holes, gives to the flute, clarionet, and even the Kent-bugle, a wide range of sound, while the trumpet is restricted to comparatively few harmonic notes.

714. All elastic substances, when vibrating, may produce musical notes; and as the manner in which they are fixed or held, as well as their form and size, must influence the manner of their vibration, it must also affect the note produced by them. Though these vibrations are usually so minute as to be invisible, they may be made to paint their picture, by their effect upon light bodies, such as particles of sand sprinkled over the vibrating surface. Such bodies will be tossed off from those spaces where the vibration is strong, and will collect in greater amount at those points or lines which remain at rest, like the knots of the violoncello-string. The dark lines in Fig. 217, represent the *lines of rest* on which sand collects when a square plate of glass with smooth-ground edges is firmly supported at its centre, by a pair of tongs or otherwise, and excited into vibration by drawing a fiddle-bow athwart the middle of one edge. By varying the form of the plate, the manner of the support, and the place of application for the bow, all kinds of fantastic figures may be produced.

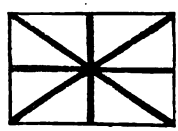

Fig. 217.

715. When a bell is struck by a hammer on its outer edge,

the part struck is driven for the moment nearer to the centre. This causes the bell to bulge out on each side, and this again drags inward towards the centre that part of the bell which lies opposite the place which receives the blow: thus the bell is changed from the circular to the elliptic form. But, by its elasticity, it almost immediately returns to its original form, and, by the momentum of its particles, becomes compressed where it was previously stretched out, and extended where it was previously compressed, until it assumes the elliptic form once more, but in a different direction; thus it continues vibrating in form between two ellipses having their long diameters at right angles to each other, and these vibrations give rise to the fundamental note of the bell. As this instrument is very variable in the shape and size of its different parts, many secondary vibrations complicate the principal motion, producing various other notes according with the fundamental note, and producing also grave harmonics.

716. You may actually observe this change of form in large bells; and when the instrument is too small for this purpose, it is still easy to prove its existence in a very beautiful manner. Take a large, thin bell-glass, with a smooth edge, fill it with water nearly to the top; then, with the fore-finger moistened and carried with gentle pressure around the margin, provoke the glass to musical vibration. Instantly the surface of the water will be covered by minute, but visible waves, arising generally from four moveable quadrants of the circumference, which follow the finger in its progress, and are separated by four points which remain relatively at rest. In addition to these principal waves produced by the pulse of the fundamental note, we often witness others, still smaller, raised by the secondary or harmonic notes. Such is the agitation thus produced that the spray of the conflicting waves sprinkles the hand of the performer, and is sometimes tossed into his face. The force of the vibration may be judged of by the fact that glasses have been frequently broken by it.

717. *Sympathetic Sounds.*—The pulses of sound being mechanical forces capable of producing vibrations in all elastic bodies on which they impinge, the succession of such forces applied at regular intervals by a musical note must continually increase the vibration in bodies capable of vibrating in the same time. Thus; if a string sounding any given note be placed near a bell, a tumbler, and another string, all in unison with this note, these instruments will feebly respond to the same tone. Place a hat on your hand,

with its top on the open palm, while a fine male singer runs over the scale of notes with his voice, and, at certain harmonic notes, the hat will be felt to tremble. Some persons are even able to break panes of window-glass, or vases, by the vibrations communicated to them by the voice. The deeper notes of large organs are felt sensibly to shake the pews, floor, and walls of churches, and sometimes cause a trembling of the very earth around a building.

718. Sympathetic vibrations thus produced add to the volume or force of the sound which causes them; and it is this which gives effect to sounding-boards and other appendages attached to musical instruments to increase their loudness. Thus; a musical box which, when held in the hand, is scarcely heard at the distance of ten feet, sounds loudly at three times that distance when placed in contact with a plate of glass or laid upon a table.

719. If a string be touched with the bow, when placed by the side of another string of one-half or one-third its length, but of the same size and tension, the reaction of the latter will almost instantly determine the spontaneous division of the former into two or three secondary parts, each in unison with the shorter string.

720. These facts will sufficiently explain the nature of sympathetic sounds, which reach their highest perfection in the æolian harp—an instrument composed of several parallel strings properly tuned upon a sounding-board or box, and designed to be placed in a variable current of air, such as the crevice of a window partly open. The air throws these strings into action alternately, producing as many various fundamental notes, and their spontaneous divisions, together with their reactions on each other sympathetically, give rise to every combination and succession of wild, ungovernable harmony.

721. *Transmission of Sound.*—The musical pulses travel always at the same rate through the same medium, so long as it continues to be of the same density, whatever may be the pitch of the notes. Were this not the case, an air or piece of music would become unintelligible at some distance from the instrument; for, some of the notes travelling faster than others, they would reach the ear in a different order from that in which they are produced, and a total overthrow of time, melody, and harmony would be inevitable. But sound moves with different velocities, in different media, or in different states of the same medium; and thus the pulses travel much more rapidly in water, dry wood, and the

metals, than in air. If the ear be applied to a rail at one end of a fence a hundred feet or more in length, when a smart blow is struck by a light hammer at the other end of the fence, the sound of the hammer will be heard twice; first, through the wood, and, a little afterwards, through the air. The speed of the pulses is dependent upon the rapidity with which the compressed particles rebound from each other by their elasticity or mutual repulsion. India rubber is called *elastic*, though it yields very little sound; because, in fact, though it recovers its form very perfectly when extended or compressed, it does so very slowly.

722. There is generally a loss in the force of sound every time that it passes from one medium to another. Thus, a piano played in a room over-head is heard indistinctly, if at all, in the parlour below; because the sounds have to pass principally from the air of the room to the planks of the floor, perhaps through a carpet; from this into the confined air above the ceiling; from this to the laths and plaster; and from these to the air of the parlour. But let a metallic rod pass from the sounding-board of the piano through the ceiling to the room below, and the music will be heard distinctly, by means of its longitudinal vibration.

723. If another sounding-board or a looking-glass be placed in contact with the lower end of the rod, the notes will be exceedingly increased in power. A glass of sparkling champagne or cider cannot be made to ring, but produces a sound like a cracked pitcher; because the pulses are confused, and the vibrations checked by the difficulty of passing continually from liquid to gas, and back again, through the mixture: but when the bubbles have all risen and been dissipated, the vessel will give a clear note.

724. Sound can hardly be communicated through partitions of heavy inelastic tapestry, feather beds, or floors laid on sawdust, but pass with comparative readiness through walls of marble, hard wood or metal. The constant and irregular change of medium, in the former cases, breaks up each original pulse into a multitude of partial, conflicting, or disordered waves, reducing sound to a mere unintelligible murmur, or entirely destroying it.

725. Sound, when confined to a medium of uniform density, is louder in proportion to that density, and travels less rapidly in the same proportion. I have already stated that its progress through the atmosphere, near the surface of the earth, is at the rate of about 1142 feet per second. This rate, however, varies a little with the changes of tempera-

ture and the vapory or *hygrometric* condition of the air. Many experiments have been made upon the rate of sound in different years and countries, in Europe, India, and the polar regions of America. The experiments generally held most accurate have been performed in Holland, and give a velocity of 1089.42 feet per second, at the temperature of freezing water. But further examination shows that the speed of sound increases about 1.14 feet for every additional degree of temperature measured by Fahrenheit's thermometer; which gives 1142 feet at the temperature of 78 degrees.

726. By means of light suddenly emitted and accompanied by sound, we can frequently determine distances with considerable accuracy. Thus, when a gun is discharged or lightning flashes, if we measure the interval of time between the flash and the report or the first thunder-clap, by means of a watch marking the seconds, and multiply the number of seconds by 1142, it will give very nearly the distance in feet—for, light travels so rapidly that we may safely disregard the interval occupied in its passage between any two places, on or near the earth's surface, which are visible from each other.

727. Numerous experiments have also been made, to determine the rate of the progress of sound through other substances than the air. Thus, two German philosophers, by observations extended to the distance of nine miles, determined that the rate in water was 4709 feet per second. M. Biot, by observation on nearly half a mile of connected cast iron water-pipes, at Paris, through which any sound could be heard twice, once through the iron and once through the air, determined the rate in the former to be $10\frac{1}{2}$ times greater than in the latter, being 11,865 feet per second. By various experiments, it has been rendered probable that the rate is not far short of $7\frac{1}{2}$ times that of air in silver, 9 times in copper, and from 11 to 17 times in wood. That the *order* of these rates is correct, there is no doubt; but the experiments from which they have been deduced are liable to some errors.

728. The distance to which sounds can be heard depends upon the conducting power of the media, and this again upon their elasticity. If the world were entirely composed of glass, hard wood, or iron, the blow of a hammer would be heard in the most distant parts of it within a few minutes. Even in the air, the human voice is sometimes heard at great distances, particularly when uttered in a shrill *falsetto* pitch. It is carried farthest over water and plain surfaces, princi-

pally because the pulses are there less broken or confused by conflicting sounds and echoes. For the same reason, it is heard at greater distances during the night. Persons of highly cultivated voice, such as teachers of elocution, have been heard distinctly amid the noises of the day, across rivers of great breadth. The "going at three shillings! going, going, gone!" of an auctioneer was heard, many years ago, from the summit of the hill in Market street, Philadelphia, to the opposite ferry in Camden, in New Jersey, nearly a mile distant, amid the noonday din of a commercial city. But the most remarkable instance on record, was the nightly "All's well!" of the sentry of Old Gibraltar, said to have been heard at New Gibraltar, ten or twelve miles distant.

729. Liquids are good conductors of sound, but are surpassed in this respect by solids. If one end of a dry stick be held against the ear, and the other be placed on the lid of a boiling kettle, the formation of the bubbles of vapour will produce sounds resembling the rattling of a dray or cart over a stony street. If a common fire-poker be suspended upon a string or ribbon, the other end of which is wound round a finger inserted into one ear, a very slight tap against the end of the iron rod will produce the loud tone of a heavy bell.

730. Heat increases the elasticity of gases, and also diminishes the weight of the vibrating columns of air in wind-instruments. Hence, sound travels more rapidly in hot than in cold air, when the barometric pressure remains the same; and the pitch of musical notes is raised or rendered sharper by heat. Thus, an organ sounds perceptibly more grave in winter than in summer; and a flute that accords perfectly with the tuning-fork, when cold, rises above concert-pitch when warmed by the breath.

731. *Organs of Voice.*—The organs of the human voice constitute a complicated musical apparatus, in which the properties of both wind and string-instruments are combined. At the upper part of the windpipe, certain vibrating chords called ligaments are stretched between moveable cartilages, just beneath the lining membrane covering the throat and the windpipe itself; which latter is a large tube filled with air, and nearly cylindrical. The moveable cartilages are provided with many very delicate muscles, by which the tension of the ligaments may be increased or diminished, and the passage of air from the tube enlarged or contracted at will. The tube itself undergoes slight changes in length, being composed chiefly of cartilaginous rings acted upon by

the muscles of the throat, &c. Add to this, that the cavities of the mouth, and nose, and, in men, certain other cavities in the bones of the skull, have an influence on the volume, quality, and pitch of the voice, producing other vibrations and echoes, while the tongue and throat, by their motions, interrupt and modify the reverberations and the succession of the voice to an almost endless extent. To be perfectly acquainted with the philosophy of language, a man should be a profound musician and a skilful anatomist.

CHAPTER VIII.

OPTICS.

732. OPTICS is the science which treats of the properties of light and vision. It is divided into a number of branches, the names of which, with their definitions, will occur as we proceed.

733. *Nature of Light.*—Light, like caloric, is imponderable. No human skill has been able to prove that it possesses weight, even when most concentrated. Until of late years, the great majority of physical investigators had considered it as an extremely elastic fluid darting in all directions from the luminous body, in lines of incalculably minute particles following each other in rapid succession, each line constituting what is termed a *ray*. These rays necessarily become continually more distant from each other as they advance, being directed to all parts of the *periphery* or surface of a sphere; and light, when permitted to spread freely, like sound, must therefore become diminished in intensity in direct proportion to the square of the distance from the luminous body. Any number of such rays forming a group or body of light sufficiently large to be measured, as when sunshine streams into a dark room, is called a *beam* or *pencil* of light. Such a pencil is seen emanating from a candle, in Fig. 218.

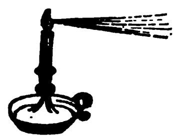

Fig. 218.

734. Almost from the origin of the science of optics, there were persons disposed to consider light as the result of impulses, like the pulses of sound, transmitted through a medium supposed to fill all space, but so exceedingly rare as

to offer no sensible resistance to the motions of the heavenly bodies. These pulses, separated from each other by various intervals, like those producing the different musical notes, were supposed to act upon the nerve of vision as the musical pulses impress the nerve of hearing.

735. Both these suppositions or *hypotheses* are surrounded with difficulties, though either of them will enable us to arrange and explain the relations of all the optical facts which can be introduced with propriety in the present work; and the doctrine of *radiation* being the more easily understood by beginners, it has been adopted here.

736. Light is derived from a variety of sources; such as, 1. the sun, the fixed stars, and articles in a state of combustion; which are bodies luminous by their own light: 2. the moon, planets, and all other visible substances upon which the light of a self-luminous body falls, and which shine by reflection. Light is also occasionally derived from chemical changes among the particles of certain bodies, called *spontaneous phosphori*, because the substance called phosphorus gives out a faint light in dark places, at moderate temperatures, which is generally, though not always, the result of a kind of slow combustion. Decayed wood and decaying animal or vegetable matter may form phosphori of this character; as is seen in light-wood, old pickle-barrels, and the bones of dead animals in certain conditions. The diamond, after long exposure to sunshine, flashes brilliantly in the dark by means of light previously absorbed; snow absorbs the sun's rays during the day, and renders the night less dark by gradually parting with them again when the sun is withdrawn:—several artificial as well as natural combinations of matter display this power in a high degree, and are thence called *solar phosphori*. Mere agitation of the particles of many substances occasions an elimination of light: thus, the friction or the sudden breaking of many crystalline minerals gives rise to bright flashes; as when loaf-sugar is broken in a dark place. Light also accompanies many electrical, magnetic, and galvanic experiments, and also many chemical changes in the structure of bodies. It is also *secreted* by peculiar organs in many living animals and plants: thus, certain plants—as the marigold, the tuberose, and the nasturtium—sometimes emit flashes from their flowers on a warm, quiet, summer evening; the fire-fly secretes light fitfully, and the glow-worm more steadily, near the tail; a few lantern-flies will enable one to read by the radiance of their beaks. Myriads of soft-bodied animals of the ocean produce

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736. Light is derived from a variety of sources; such as, 1, the sun, the fixed stars, and articles in a state of combustion; which are bodies luminous by their own light: 2, the moon, planets, and all other visible substances upon which the light of a self-luminous body falls, and which shine by reflection. Light is also occasionally derived from chemical changes among the particles of certain bodies, called *spontaneous phosphori*, because the substance called phosphorus gives out a faint light in dark places, at moderate temperatures, which is generally, though not always, the result of a kind of slow combustion. Decayed wood and decaying animal or vegetable matter may form phosphori of this character; as is seen in light-wood, old pickle-barrels, and the bones of dead animals in certain conditions. The diamond, after long exposure to sunshine, flashes brilliantly in the dark by means of light previously absorbed; snow absorbs the sun's rays during the day, and renders the night less dark by gradually parting with them again when the sun is withdrawn:—several artificial as well as natural combinations of matter display this power in a high degree, and are thence called *solar phosphori*. Mere agitation of the particles of many substances occasions an elimination of light: thus, the friction or the sudden breaking of many crystalline minerals gives rise to bright flashes; as when loaf-sugar is broken in a dark place. Light also accompanies many electrical, magnetic, and galvanic experiments, and also many chemical changes in the structure of bodies. It is also *secreted* by peculiar organs in many living animals and plants: thus, certain plants—as the marigold, the tuberose, and the nasturtium—sometimes emit flashes from their flowers on a warm, quiet, summer evening; the fire-fly secretes light fitfully, and the glow-worm more steadily, near the tail; a few lantern-flies will enable one to read by the radiance of their beaks. Myriads of soft-bodied animals of the ocean produce

"the lightning of the waters," flashing under the bows of a ship and around the oars of a boat, and sometimes causing the track of a vessel to resemble a nether milky way, studded with suns, planets, and luminous nebulæ. From whatever source light may be derived, it has certain properties in common. Let us examine them.

737. *Velocity of Light.*—Wherever we have an opportunity of observing the progress of light through sufficient distances, we find its velocity uniform, like that of sound. It travels 191,919 miles, or about 192,000 miles per second. This is ascertained in the following manner: The planet Jupiter has four moons or satellites, which are frequently eclipsed by the body of the planet passing between one of the moons and the eye of the observer; and the moment of occurrence of each of these eclipses is calculated with great accuracy by astronomers. Now, this planet and the earth revolve around the sun in planes pretty nearly coinciding with each other. Sometimes, eclipses occur when Jupiter and the earth are in *conjunction*, or on the same side of the sun, forming nearly a straight line with it; at other times, when the earth and planet are in *opposition*, or on opposite sides of the sun, forming nearly a straight line with it. In the former, the earth is nearer to the planet than in the latter case, by a distance equal to the diameter of the earth's orbit, which is known to be 190,000,000 of miles. When these bodies are in conjunction, an eclipse of one of Jupiter's moons is seen 16½ minutes sooner than when they are in opposition: hence; light conveys the intelligence of the eclipse to the eye, across the earth's orbit, or 190,000,000 of miles, in 16½ minutes, which is at the rate of a little more than 191,919 miles per second.

738. *Refraction of Light.*—Light, when uninterrupted and uninfluenced by matter, always travels in straight lines; as when it passes from the sun or moon to the earth's atmosphere. It also travels in straight lines when passing through any medium of uniform density. Thus; if the eye be sunk below the surface of water, all visible objects within the liquid itself are seen in their proper places; because the rays emanating from them come *directly* to the eye. So; rays traversing a sheet or body of glass, preserve a straight course from one surface to the other.

739. But when a ray or beam of light passes from a denser into a rarer medium, or from a rarer into a denser medium, unless it fall perpendicularly upon the surface, it is always bent from its direct course at an angle which varies in differ-

appear above the horizon, at S′, in consequence of its parallax.

742. *Inflection of Light.*—When rays of light pass very near to the edge of any body, they seem to be somewhat bent from their course, as if by the attraction of the matter composing the body, and thus, the shadows of objects are prevented from being perfectly black. This species of bending is called the *inflection* of light.

743. *Reflection of Light.*—Light being highly elastic, its particles, when they cannot pass between the molecules or atoms of a body upon the surface on which they fall, necessarily rebound from it, like billiard-balls, with their velocity unchanged, making the angle of reflection equal to the angle of incidence. If, then, a ray of light, A B, Fig. 221, fall upon the plain surface E F, and cannot enter, it will rebound in the direction B C; and if the surface F F be perfectly smooth, the ray will be visible, after reflection, in no other direction. But all surfaces, however smoothly polished, still present minute inequalities; and even when parallel rays of light fall upon the most highly polished body, they must strike upon these inequalities at every possible angle; therefore, some of the rays will be scattered in every possible direction by reflection from each visible portion of any surface. So extremely minute are the particles of light that they are continually reflected, not only from particles of dust floating in the air, but from the molecules of the air themselves. A beam of sunshine in a dark room thus becomes visible throughout its whole course. The diverging beams of the sun, shining through openings in the clouds, producing the appearance usually called "the sun drawing water," present us with this atmospheric reflection on a large scale; and the rays falling upon the molecules of the upper air, after sunset, are tossed about and scattered in the same manner, so as to diffuse a gentle light even upon the earth below. This is the cause of twilight.

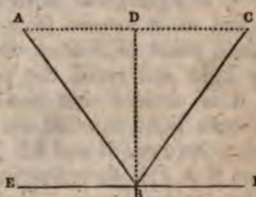

Fig. 221.

744. *Of Shadows and Penumbræ.*—The form of the shadows of objects depends upon the rectilinear direction of the rays of light, modified by inflection and refraction. They present the outlines of the objects variously distorted, enlarged, or diminished, according to the form of the surface

empty basin as far as F; but, on filling it with water to the former level, the light passes down to E: because the ray C D, just passing the rim of the vessel, falls on the surface of the denser medium at D, and is there bent at the same angle as in the former experiment, and inclining more towards the perpendicular, assumes the direction D E. This bending of rays, as they pass from a medium of one degree of density to another of different density, is called *refraction*.

741. *Parallax.*—In the foregoing experiments, the rays are bent at an angle, but the portion of each ray contained in either medium is always found to pursue a straight line, because each medium is uniform in density throughout. When rays pass successively and obliquely through the different strata of the atmosphere, the density of the medium through which they travel is perpetually changing, because the air continually diminishes in density as we ascend. Such rays must, therefore, undergo a change of refraction at every moment. In approaching the earth, they will be continually bent more *towards the perpendicular direction*, because the density is continually increasing; but in leaving the earth, they will be perpetually bent more from the perpendicular direction, because the density is as constantly diminishing. Such rays, therefore, pursue a curvilinear direction, and consequently no object can appear to us in exactly its proper place when viewed through a great height or depth of air, unless when we look directly up or directly down upon it. The apparent place of the sun or a star is never its true place in the heavens, except when it is exactly at the zenith; and the angular distance between the apparent and real place of a heavenly body is called the *parallax*. As the degree of refraction increases with the angle of incidence of the ray, it follows that the nearer a heavenly body approaches the horizon, the greater will be its parallax, and it will continue visible even after it sinks actually below the horizon. Let D, Fig. 220, represent a portion of the earth's surface; B C, a section of its atmospere; A, the place of an observer; A H, a horizontal line; and S, the sun, when just below the horizon. Now, a ray taking the direction S F, and meeting the atmosphere about E, would be curved by refraction until it would reach the eye at A, in the direction S A, and the sun would therefore

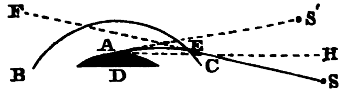

Fig. 220.

and E the earth. When the moon—a comparatively small body—comes directly between the earth and the sun, the rays A C and B C, from opposite sides of the sun, converge towards a point beyond C, and bound the true shadow of the moon, M C, which is therefore conical. This shadow, in the present instance, is arrested by the surface of the earth, and forms a dark circle thereon at C, within which circle an observer cannot see any portion of the sun, and the eclipse will therefore be *total*. The rays B D and A F, crossing each other at an angle and touching the surface of the moon at points or sides opposite to their respective origins, bound the half-shaded space between M and E, which constitutes the penumbra, forming part of an inverted cone, of which the base, D F, where it is arrested by the earth, forms a large circle, enclosing the dark spot C; and throughout this space, only part of the sun can be seen, rendering the eclipse *partial*. As the orbits of the earth and moon are elliptical, their distance from each other and from the sun at different periods varies considerably. Now, if it so happen that the moon is nearly at her greatest distance from the earth (or in *apogee*), and the earth near its least distance from the sun (or in *perihelion*), at the time of such an eclipse, the rays A C and B C will cross each other before they reach the earth, so that the shadow disappears, and the penumbra alone falls upon the earth. In this case, all observers would witness a partial eclipse, but one standing at C or any where between the rays just mentioned, would see the moon like a dark circle over the face of the sun, while the rest of the sun's disk would appear as a shining ring around it, constituting what is called an *annular eclipse*. The planets Mercury and Venus, being nearer to the sun than the earth, sometimes produce annular eclipses; but their apparent size is so small, compared with that of the sun, that their true shadows never reach the earth, and their passages across its face are called *transits*. The earth would appear to perform similar transits to observers upon either of the more distant planets.

747. The facility with which light passes through different bodies that permit it to pass at all, does not depend upon the density or closeness of their particles: thus, charcoal, with a very low specific gravity, transmits scarcely a ray of light, while the diamond, composed of the same kind of matter in much greater density, permits nearly all the rays that fall on it perpendicularly, to continue their course unchecked. The molecules of light are supposed to be so

on which they fall, its distance from the object, and the relative sizes of the object and the luminous body which casts them. If the luminous body be larger than the object, the shadow continually increases in size with distance; but if it be smaller than the object, the shadow diminishes with distance, and if not arrested by a reflecting surface, finally dwindles to a point and disappears.

745. As light radiates in all directions from every part of a luminous body, there must be formed around every shadow a margin or border of half-shade, called a *penumbra*, and formed in a manner explained by Fig. 222. S represents the sun shining upon the surface M N, and casting thereon a shadow of an upright object, A B, impervious to light. The ray C F strikes the surface at F, and as it comes from the highest point of S from which any light can reach the point A, it is obvious that none of the sun's light can fall on the surface between B and F. The space B A F is therefore in deep shadow. From F towards I, the surface receives continually more light from the sun, but it is only at I that the ray E I, from the farthest part of the under surface of the sun, reaches the surface M N. The space F A I is therefore partially illuminated, the quantity of light being gradually increased from complete shadow at F to broad sunshine at I. This space is the *penumbra* or half-shadow; and as it is bounded by rays that cross at an angle at A, it must continue to increase in size with distance, whatever may be the relation in size between the object and the luminous body.

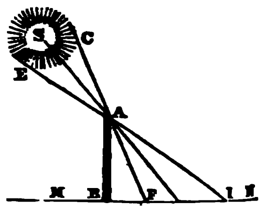

Fig. 222.

746. The true shadow and the penumbra play important

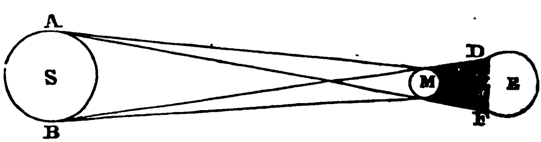

Fig. 223.

parts in the phenomena of eclipses. Fig. 223 is a diagram of an eclipse of the sun; in which S is the sun, M the moon,

and E the earth. When the moon—a comparatively small body—comes directly between the earth and the sun, the rays A C and B C, from opposite sides of the sun, converge towards a point beyond C, and bound the true shadow of the moon, M C, which is therefore conical. This shadow, in the present instance, is arrested by the surface of the earth, and forms a dark circle thereon at C, within which circle an observer cannot see any portion of the sun, and the eclipse will therefore be *total.* The rays B D and A F, crossing each other at an angle and touching the surface of the moon at points or sides opposite to their respective origins, bound the half-shaded space between M and E, which constitutes the penumbra, forming part of an inverted cone, of which the base, D F, where it is arrested by the earth, forms a large circle, enclosing the dark spot C; and throughout this space, only part of the sun can be seen, rendering the eclipse *partial.* As the orbits of the earth and moon are elliptical, their distance from each other and from the sun at different periods varies considerably. Now, if it so happen that the moon is nearly at her greatest distance from the earth (or in *apogee*), and the earth near its least distance from the sun (or in *perihelion*), at the time of such an eclipse, the rays A C and B C will cross each other before they reach the earth, so that the shadow disappears, and the penumbra alone falls upon the earth. In this case, all observers would witness a partial eclipse, but one standing at C or any where between the rays just mentioned, would see the moon like a dark circle over the face of the sun, while the rest of the sun's disk would appear as a shining ring around it, constituting what is called an *annular eclipse.* The planets Mercury and Venus, being nearer to the sun than the earth, sometimes produce annular eclipses; but their apparent size is so small, compared with that of the sun, that their true shadows never reach the earth, and their passages across its face are called *transits.* The earth would appear to perform similar transits to observers upon either of the more distant planets.

747. The facility with which light passes through different bodies that permit it to pass at all, does not depend upon the density or closeness of their particles: thus, charcoal, with a very low specific gravity, transmits scarcely a ray of light, while the diamond, composed of the same kind of matter in much greater density, permits nearly all the rays that fall on it perpendicularly, to continue their course unchecked. The molecules of light are supposed to be so

extremely minute, when compared with the intervals between the molecules of the densest ponderable matter, that a large proportion of all the rays falling upon any body may penetrate to a certain depth between them before they meet with an obstacle. Now, it is evident that this depth may depend upon the arrangement as well as the number of molecules of matter in the ponderable body: thus; the diamond may offer numerous passages to light, while, in charcoal, the particles may offer impenetrable barriers to its progress, almost at the surface.

748. Bodies that reflect light regularly, but permit it to pass freely in other respects, allow the forms of objects to be seen through them distinctly, and are called *transparent;*—as polished glass. Those of which the particles scatter the rays irregularly, so as to confuse all images, yet still permit the light to struggle through, are called *translucent;*—as ground glass. When nearly all the light is arrested by a body, or reflected back to its surface from a scarcely visible depth, the body is said to be *opaque;*—as iron.

749. *Absorption of Light.*—No substance in nature is absolutely impervious to light. Gold and silver, which are among the densest of known substances, become translucent, and the former even transparent, when rendered very thin. The light of day penetrates a wooden window-shutter, so as to render the outlines of objects visible to extremely acute eyes, even in a darkened room.

750. On the other hand, no substance is perfectly transparent. Noonday sunshine loses one-fourth of its intensity by passing perpendicularly through the clearest atmosphere to the level of the sea, and appears much brighter on a mountain top. We gaze upon the sun without pain or difficulty, at its rising or setting, because the rays then traverse the atmosphere for a much greater distance, and come to us with only 1-212th of their original intensity. From these facts it is evident that light, in passing through the most transparent bodies, is *absorbed* to a greater or less extent, according to the degree of their transparency, and the thickness traversed by the rays.

751. It has been proved that sunlight loses about one-half its intensity by passing through fifteen feet of clear sea-water, or through three inches of the clearest glass. Gold, reduced to the thickness of 1-300,000th of an inch, transmits a beautiful sea-green light, like the colour of the melted metal, and is thought to be 250,000 times more opaque than glass. Writing-paper transmits about one-third of the incident light,

diffused or scattered by its translucency; and when oiled, it becomes transparent, but transmits scarcely any more light. Glass, when ground and translucent, gives passage to nearly as much light as it does when polished and transparent.

752. *Of Colour and Images.*—As objects are rendered visible by the light reflected from them or transmitted by them, it follows that colours are not resident in the bodies to which they appear to belong, but are mere sensations produced in us by the properties of light, and not by those of ponderable matter. There must, therefore, exist many varieties in the condition of light under different circumstances, or it could not produce in us such various sensations.

753. These varieties are explained on the hypothesis of *undulation* (734), by supposing that the pulses of light, like those of sound, produce effects varying with the rapidity of the succession of the undulations, which may be modified by the reflecting or the refracting body: but on the hypothesis of radiation, it is necessary to consider light as a compound body, a molecule of white light being composed of several different kinds of atoms, each awakening the idea of a certain colour, but, when all combined, producing the sensation of whiteness.

754. When molecules of light fall upon or are transmitted through bodies, their component atoms—some of which are always reflected, others absorbed, and others, in most cases, transmitted—are separated and reunited in various proportions, according to the nature of the body, so as to produce every variety of tint. This explains why the images of things formed by reflection and refraction,—a subject which will be more fully discussed hereafter—are sometimes coloured after nature, and sometimes appear in hues modified by the body which forms them.

755. When sunshine enters a dark room, through a small circular hole in a window-shutter, the rays coming from all parts of the sun towards this hole must necessarily spread out in the form of a cone after crossing each other at the orifice, and make a circular illumination upon the perpendicular wall on the other side of the room; as represented in Fig. 224; where S designates the sun, O the orifice, and F the illuminated circle. Light emanating from other objects around the luminous cone A B O will also enter the orifice, and will diffuse, over the surrounding parts of the wall, rays varying in colour according to the nature of the object from which they emanate. In other words, the bright spot F will be an image of the sun, visible in all parts of the room by

of a semicircle, will measure 90° or a right angle (57). The angle B D E is therefore the angle of incidence (308). Now, lay off from E the arc E A, making it equal to E B, and join D A : then, the angle E D A, being equal to the angle B D E, will be the angle of reflection, and the line D A will represent the direction of the reflected ray.

762. When the mirror is concave, and spherical, as at M N, Fig. 227, find the centre, C, of the curve M N. All radii of a circle are perpendicular to the surface at the point of intersection. Therefore, join C D, and B D C will be the angle of incidence. Draw D A, making an angle with D C equal to this angle of incidence, and D A will represent the reflected ray.

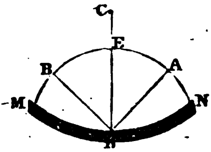

Fig. 227.

763. If the mirror be convex and spherical, as at M N, Fig. 228, find the centre, as before, join C D and produce it to E. Then D E will be perpendicular to the surface at D. Make the angle A D E equal to the angle E D B, and D A will represent the direction of the reflected ray.

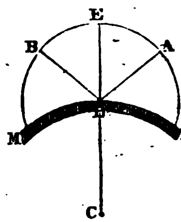

Fig. 228.

764. In all mirrors, however irregular, if a ray of light fall upon any point, and a line be drawn perpendicular to the surface at the point of incidence, the angle of reflection can be found by the same process.

765. When light falls perpendicularly upon a mirror, it is reflected in the very line of incidence. Thus, in either of the foregoing figures, a ray pursuing the direction E D, would be reflected in the direction D E, because, in this case, the angles of incidence and reflection have vanished, or are each equal to nothing. If a ray fall in the direction of a tangent to any surface, it cannot be reflected, because it has the same direction with the surface, and cannot impinge upon it.

766. When parallel rays impinge upon a plain mirror, they will continue parallel after reflection. Let A A′, Fig. 229, represent two parallel rays incident upon the mirror M N, at *the points* D, D′. Draw,

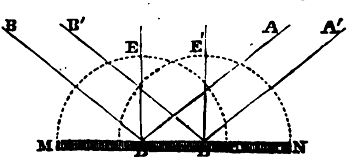

Fig. 229.

to offer no sensible resistance to the motions of the heavenly bodies. These pulses, separated from each other by various intervals, like those producing the different musical notes, were supposed to act upon the nerve of vision as the musical pulses impress the nerve of hearing.

735. Both these suppositions or *hypotheses* are surrounded with difficulties, though either of them will enable us to arrange and explain the relations of all the optical facts which can be introduced with propriety in the present work; and the doctrine of *radiation* being the more easily understood by beginners, it has been adopted here.

736. Light is derived from a variety of sources; such as, 1. the sun, the fixed stars, and articles in a state of combustion; which are bodies luminous by their own light: 2. the moon, planets, and all other visible substances upon which the light of a self-luminous body falls, and which shine by reflection. Light is also occasionally derived from chemical changes among the particles of certain bodies, called *spontaneous phosphori*, because the substance called phosphorus gives out a faint light in dark places, at moderate temperatures, which is generally, though not always, the result of a kind of slow combustion. Decayed wood and decaying animal or vegetable matter may form phosphori of this character; as is seen in light-wood, old pickle-barrels, and the bones of dead animals in certain conditions. The diamond, after long exposure to sunshine, flashes brilliantly in the dark by means of light previously absorbed; snow absorbs the sun's rays during the day, and renders the night less dark by gradually parting with them again when the sun is withdrawn:—several artificial as well as natural combinations of matter display this power in a high degree, and are thence called *solar phosphori.* Mere agitation of the particles of many substances occasions an elimination of light: thus, the friction or the sudden breaking of many crystalline minerals gives rise to bright flashes; as when loaf-sugar is broken in a dark place. Light also accompanies many electrical, magnetic, and galvanic experiments, and also many chemical changes in the structure of bodies. It is also *secreted* by peculiar organs in many living animals and plants: thus, certain plants—as the marigold, the tuberose, and the nasturtium—sometimes emit flashes from their flowers on a warm, quiet, summer evening; the fire-fly secretes light fitfully, and the glow-worm more steadily, near the tail; a few lantern-flies will enable one to read by the radiance of their beaks. Myriads of soft-bodied animals of the ocean produce

from A D to A B, the virtual image B would continue to be visible from A, although the real object could not be seen: thus; a lady in her parlour may sometimes examine a visitor at the door, by looking at her mirror in the parlour.

769. In the foregoing example, the object is placed in a position perpendicular to the mirror. If it be placed in an inclined position, the inclination is still reversed, but it will not be turned end for end, as before. This you will perceive at a glance, by examining Fig. 231. In a mirror inclined to the horizon, at an angle of forty-five degrees, as at M N, Fig. 231, if the object be erect, the image will be horizontal; but, if the former be horizontal, the latter will be erect.

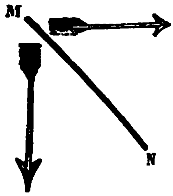

Fig. 231.

770. Images in mirrors, like real objects, appear to enlarge as we approach, and diminish as we retreat from them. The reason of this will be obvious on examining the reflected rays B E A, C F A, &c., and the half-virtual, half-real rays B′ E A, C′ F A, &c., Fig. 230; for, if the eye approach or recede from the mirror, the convergence of these rays will be proportionally increased or diminished; and it is this convergence alone which determines the apparent size of the object or the image. Similar effects must obviously follow the removal or approach of the object instead of the eye. Hence, images in plain mirrors always appear as if equally distant, and of the same dimensions with the real object. Hence, also, an observer sees the whole of his own image in a plane mirror of half his length: because the *visual rays* emanating from his person to form the image by reflection, perform half their journey in reaching the mirror, and the other half in returning to the eye.

771. It is evident, from a glance at the same figure, that just as converging rays falling on a plane mirror continue to converge after reflection, so also diverging rays continue to diverge, under similar circumstances.

772. Hitherto, we have considered the human eye as nearly a point in space, receiving but a single ray of light from each minute portion of the surface of an object: but that part of the eye which admits light is really of considerable size, and is capable of receiving many rays diverging from the same place. Let A B, Fig. 232, represent a plane mirror, M N an object placed before it, and E the eye of an observer. Here, the divergent rays in the pencil M D F,

will form, after reflection, a continuation of the same pencil from D F to E, and all these rays will enter the eye.

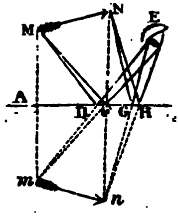

Fig. 232.

773. Now, the eye is so constructed internally that all the rays received by it from the same spot on an object not too near to be seen distinctly, are concentrated by refraction to a single spot within it, just as they reach the *retina*—an expansion of the *optic nerve*, by means of which the mind perceives the presence of light. Therefore, the whole conical pencil of rays M D F E, in the figure, is concentrated upon a single spot on the retina, and the mind perceives the spot M, illuminated by all these rays, in the direction of the axis of that cone. If the reflected portions of this cone, and the similar cone N G H E, be produced beyond the mirror, they will form points at *m* and *n*, and will mark the extent and position of a virtual image of M N, as seen from E.

774. When parallel rays fall on a convex mirror, as in Fig. 233, they diverge after reflection. Let M N represent the mirror, C the centre of its curvature, and A, A, A, three equidistant rays of parallel light, of which one ray, A D, corresponds with the axis of the mirror. From the centre, C, to the points of incidence, M, D, and N, draw the radii C M, C D, C N, and produce C M and C N to E and E′. Make the angles B M E and B′ N E equal to the angles E M A, E′ N A; then will M B and N B′ represent the corresponding rays after reflection (763). The ray A D, falling perpendicularly upon the surface at D, will be reflected directly back in the direction D A (763). Here, you perceive that the convex form of the surface renders the rays strongly divergent by reflection.

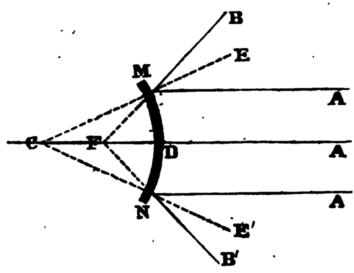

Fig. 233.

775. If the lines B M and B′ N be produced till they meet at an angular point, that point will be found, at F, in the line C A, which is the axis of the mirror. If any other pair of parallel incident rays equidistant from the axis be produced in the same manner, they will meet at some point

[illegible] sufficiently true for most practical purposes.

[illegible] *Reflection from Convex Mirrors.*—When divergent rays fall upon a convex mirror, it is obvious that they must diverge still more after reflection; and hence, the virtual [illegible] must be proportionally nearer to the mirror than the principal focus. But, if the incident rays be convergent, they will necessarily be less divergent after reflection than parallel rays, and their virtual focus will be proportionally farther from the mirror than is the principal focus. [illegible] be parallel after reflection, it is evident [illegible]

[illegible] When an object is placed before a convex mirror, it presents to the eye a diminished image of the object, apparently placed at a distance behind the surface, inversely proportional to the degree of convexity.

Thus, let A B, Fig. 234, represent a convex mirror, and M N an object before it, viewed by reflection from E, C being the centre of curvature. The eye at E perceives the point M in the direction of the axis of the reflected part of the pencil of visual rays emanating from that point; which reflected part is represented by the space D F E. Produce the lines E D and E F, until they meet in *m*, and it is evident that all the rays in the real pencil M D F E will appear to converge in the point *m*, which will therefore be the apparent place of M, one extremity of the real object M N. For like reasons, *n* will be the apparent place of the extremity N of the real object; hence, *m* N will be the place of the virtual image of the object M N, as it will be seen by reflection at E. But, as diverging rays falling upon a convex mirror are rendered more divergent by reflection (776), it is evident that *m* D and *m* F, representing reflected rays, are more divergent than M D and M F, representing incident rays: the former,

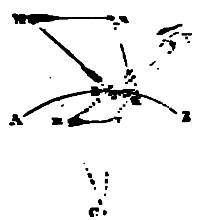

Fig. 234.

if produced, will therefore meet at an angle sooner than the latter, and hence *m* will be nearer the mirror than M. As this is equally true of any other point in *m n*, when compared with the corresponding point in M N, the whole of the virtual image will appear nearer than the real object, in proportion to the degree of convexity. As the virtual focus of each pencil of reflected rays must be nearly at the same distance from the mirror (775), the virtual image will not be straight, as represented in the figure, but curved into a convexity corresponding with that of the mirror itself.

779. In Fig. 234, however the position of the eye may be changed, while that of the object M N remains unchanged, the image *m n* will be seen in the same position. If we join M C and N C, and then cause the object to approach or recede from the centre C, keeping its direction constantly parallel to the first position, the image *m n* will increase or diminish in size accordingly; but the points *m* and *n* will always be found somewhere in the lines M C and N C. When the object is indefinitely distant, so that the incident rays may be regarded as parallel, the image will be found half-way between C and the surface of the mirror—that being the virtual focus of rays reflected from parallel incidence on such a mirror, as seen in Fig. 233.

780. On a cylindrical mirror, the rays reflected lengthwise of the cylinder are reflected as from a plain mirror, and the parts of a virtual image, which are painted by such rays, appear of undiminished size; but those parts which are painted by rays reflected in a plane perpendicular to the axis of the cylinder, will be diminished in length according to the law of convex mirrors. From this circumstance, all images of objects seen in cylindrical mirrors are strangely distorted by being diminished in the transverse, but not in the longitudinal direction; and the distortion is greatly increased by the nearest portions of the object being much less diminished in size than the more distant parts, as is also the case in spherical convex mirrors.

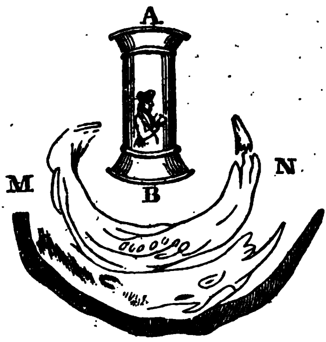

Fig. 235.

781. The nature of these distortions is varied by chan-

ging the shape of the mirror, but as the law of reflection is absolute under all circumstances, it is possible, by means of a deformed drawing laid before a distorting mirror, to produce a symmetrical image. Thus the seemingly [illegible] lines [illegible] between M and N, Fig. [illegible], will [illegible] by reflection from the cylindrical mirror a b, a perfect [illegible] picture [illegible] student reading a book.

7[illegible]. *Reflection from Concave Mirrors.*—Parallel rays of light falling upon the surface of a concave spherical mirror will be reflected nearly to a true focus situated [illegible] half way between the centre of curvature and the surface of the mirror, like the virtual focus in convex mirrors [illegible]. In this case, the focus is *actual*, and not virtual, being really formed by the meeting of the reflected rays, and not by the ideal production of the incident rays.

7[illegible]. Divergent rays falling on such a mirror, are reflected to a focus more distant from the mirror than the *principal focus* of the parallel rays. Let m n, Fig. [illegible], represent the mirror, A, the radiant point of the diverging rays, C, the centre of curvature, and F the focus of the diverging rays.

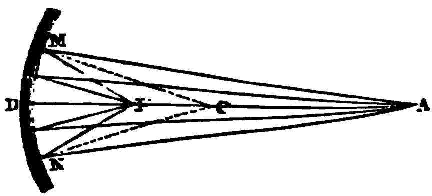

Fig. 226.

As the angles of incidence, A M C, A N C, are less than the angles of incidence of parallel rays, the angles of reflection, C M F, C N F must be also less than those of parallel rays; and hence they cannot so soon reach their angular point or focus, F. This must therefore be farther from the mirror than is the principal focus. If A approach the mirror, the angles of incidence will continually diminish, and the focus F will therefore retreat towards C. When A arrives at C, the rays all become radii to the sphere, and, falling on the mirror perpendicularly, are reflected back to C. When A advances to F, the focus retreats to A; and this constant reciprocal relation between the radiant point and the focus of diverging rays causes opticians to call the variable points A and F, *conjugate foci* of the concave mirror. When A advances still nearer to the mirror, and reaches the principal focus, the rays will be reflected in parallel directions, and the focus may be said to be infinitely

and E the earth. When the moon—a comparatively small body—comes directly between the earth and the sun, the rays A C and B C, from opposite sides of the sun, converge towards a point beyond C, and bound the true shadow of the moon, M C, which is therefore conical. This shadow, in the present instance, is arrested by the surface of the earth, and forms a dark circle thereon at C, within which circle an observer cannot see any portion of the sun, and the eclipse will therefore be *total.* The rays B D and A F, crossing each other at an angle and touching the surface of the moon at points or sides opposite to their respective origins, bound the half-shaded space between M and E, which constitutes the penumbra, forming part of an inverted cone, of which the base, D F, where it is arrested by the earth, forms a large circle, enclosing the dark spot C; and throughout this space, only part of the sun can be seen, rendering the eclipse *partial.* As the orbits of the earth and moon are elliptical, their distance from each other and from the sun at different periods varies considerably. Now, if it so happen that the moon is nearly at her greatest distance from the earth (or in *apogee*), and the earth near its least distance from the sun (or in *perihelion*), at the time of such an eclipse, the rays A C and B C will cross each other before they reach the earth, so that the shadow disappears, and the penumbra alone falls upon the earth. In this case, all observers would witness a partial eclipse, but one standing at C or any where between the rays just mentioned, would see the moon like a dark circle over the face of the sun, while the rest of the sun's disk would appear as a shining ring around it, constituting what is called an *annular eclipse.* The planets Mercury and Venus, being nearer to the sun than the earth, sometimes produce annular eclipses; but their apparent size is so small, compared with that of the sun, that their true shadows never reach the earth, and their passages across its face are called *transits.* The earth would appear to perform similar transits to observers upon either of the more distant planets.

747. The facility with which light passes through different bodies that permit it to pass at all, does not depend upon the density or closeness of their particles: thus, charcoal, with a very low specific gravity, transmits scarcely a ray of light, while the diamond, composed of the same kind of matter in much greater density, permits nearly all the rays that fall on it perpendicularly, to continue their course unchecked. The molecules of light are supposed to be so

extremely minute, when compared with the intervals between the molecules of the densest ponderable matter, that a large proportion of all the rays falling upon any body may penetrate to a certain depth between them before they meet with an obstacle. Now, it is evident that this depth may depend upon the arrangement as well as the number of molecules of matter in the ponderable body: thus; the diamond may offer numerous passages to light, while, in charcoal, the particles may offer impenetrable barriers to its progress, almost at the surface.

748. Bodies that reflect light regularly, but permit it to pass freely in other respects, allow the forms of objects to be seen through them distinctly, and are called *transparent*;—as polished glass. Those of which the particles scatter the rays irregularly, so as to confuse all images, yet still permit the light to struggle through, are called *translucent*;—as ground glass. When nearly all the light is arrested by a body, or reflected back to its surface from a scarcely visible depth, the body is said to be *opaque*;—as iron.

749. *Absorption of Light.*—No substance in nature is absolutely impervious to light. Gold and silver, which are among the densest of known substances, become translucent, and the former even transparent, when rendered very thin. The light of day penetrates a wooden window-shutter, so as to render the outlines of objects visible to extremely acute eyes, even in a darkened room.

750. On the other hand, no substance is perfectly transparent. Noonday sunshine loses one-fourth of its intensity by passing perpendicularly through the clearest atmosphere to the level of the sea, and appears much brighter on a mountain top. We gaze upon the sun without pain or difficulty, at its rising or setting, because the rays then traverse the atmosphere for a much greater distance, and come to us with only 1-212th of their original intensity. From these facts it is evident that light, in passing through the most transparent bodies, is *absorbed* to a greater or less extent, according to the degree of their transparency, and the thickness traversed by the rays.

751. It has been proved that sunlight loses about one-half its intensity by passing through fifteen feet of clear sea-water, or through three inches of the clearest glass. Gold, reduced to the thickness of 1-300,000th of an inch, transmits a beautiful sea-green light, like the colour of the melted metal, and is thought to be 250,000 times more opaque than glass. Writing-paper transmits about one-third of the incident light,

diffused or scattered by its translucency; and when oiled, it becomes transparent, but transmits scarcely any more light. Glass, when ground and translucent, gives passage to nearly as much light as it does when polished and transparent.

752. *Of Colour and Images.*—As objects are rendered visible by the light reflected from them or transmitted by them, it follows that colours are not resident in the bodies to which they appear to belong, but are mere sensations produced in us by the properties of light, and not by those of ponderable matter. There must, therefore, exist many varieties in the condition of light under different circumstances, or it could not produce in us such various sensations.

753. These varieties are explained on the hypothesis of *undulation* (734), by supposing that the pulses of light, like those of sound, produce effects varying with the rapidity of the succession of the undulations, which may be modified by the reflecting or the refracting body: but on the hypothesis of radiation, it is necessary to consider light as a compound body; a molecule of white light being composed of several different kinds of atoms, each awakening the idea of a certain colour, but, when all combined, producing the sensation of whiteness.

754. When molecules of light fall upon or are transmitted through bodies, their component atoms—some of which are always reflected, others absorbed, and others, in most cases, transmitted—are separated and reunited in various proportions, according to the nature of the body, so as to produce every variety of tint. This explains why the images of things formed by reflection and refraction,—a subject which will be more fully discussed hereafter—are sometimes coloured after nature, and sometimes appear in hues modified by the body which forms them.

755. When sunshine enters a dark room, through a small circular hole in a window-shutter, the rays coming from all parts of the sun towards this hole must necessarily spread out in the form of a cone after crossing each other at the orifice, and make a circular illumination upon the perpendicular wall on the other side of the room; as represented in Fig. 224; where S designates the sun, O the orifice, and F the illuminated circle. Light emanating from other objects around the luminous cone A B O will also enter the orifice, and will diffuse, over the surrounding parts of the wall, rays varying in colour according to the nature of the object from which they emanate. In other words, the bright spot F will be an image of the sun, visible in all parts of the room by

Then, by the above law, A D has always a fixed ratio to B E, whatever the angle of incidence may be. Thus: in certain specimens of glass, if we multiply the length of B E by 1·5, the product will be the length of A D, or if we divide the length of A D by the same sum, the quotient will be the length of B E.

792. When A C coincides with P C, A D vanishes or becomes=0, and hence B E must also vanish: therefore, rays that fall perpendicularly upon a refracting surface are not refracted at all. If A C approach indefinitely near to M C, it will be refracted to F, making the sine F G : A C or M C :: 1 : 1·5, or as 2 : 3. When A C coincides with M C, the ray ceases to be incident, and cannot be refracted. This quantity, 1·5, is called *the index of refraction*, for the peculiar glass above mentioned.

793. The index of refraction varies with the nature of the medium; but when we know the index for any particular kind of matter, it is easy to find the direction of any incident ray on entering or passing from such a medium. The index for atmospheric air is 1·000294; for water, 1·336; for the different kinds of glass, from 1·552 to 2·028; for the diamond, 2·439; and for realgar, the most powerful refractor now known, 2·549.

794. The rays of light, on leaving a denser medium, are bent from the perpendicular, just as strongly as they are bent towards the perpendicular on entering a denser medium.

795. *Of Total Refraction.*—It has been already stated that a quantity of light increasing with the obliquity of the incident rays, is reflected even from the surfaces of transparent bodies (785); but when rays pass from a rare medium, such as the air, into a dense medium, like glass, they may fall so obliquely upon a second surface of this medium, that they cannot again pass out of it, but will be totally reflected into its substance, as though the second surface were an opaque mirror.

796. Let L M N, Fig. 241, be a regular triangular prism, with an index of refraction of 1·5. Then, if A B be a ray of light incident upon the side L N at B, it will be bent towards the perpendicular I K, by refraction, and will take the direction B C. But B C falls so obliquely upon the internal surface M N, that if it could pass from the prism it would be refracted in the direction C D. Any other ray, parallel to A B, which could reach M N, would be also refracted in the direction C D. Now, in this direction, the ray cannot immediately leave the glass; and whenever this is the case,

to offer no sensible resistance to the motions of the heavenly bodies. These pulses, separated from each other by various intervals, like those producing the different musical notes, were supposed to act upon the nerve of vision as the musical pulses impress the nerve of hearing.

735. Both these suppositions or *hypotheses* are surrounded with difficulties, though either of them will enable us to arrange and explain the relations of all the optical facts which can be introduced with propriety in the present work; and the doctrine of *radiation* being the more easily understood by beginners, it has been adopted here.

736. Light is derived from a variety of sources; such as, 1. the sun, the fixed stars, and articles in a state of combustion; which are bodies luminous by their own light: 2. the moon, planets, and all other visible substances upon which the light of a self-luminous body falls, and which shine by reflection. Light is also occasionally derived from chemical changes among the particles of certain bodies, called *spontaneous phosphori*, because the substance called phosphorus gives out a faint light in dark places, at moderate temperatures, which is generally, though not always, the result of a kind of slow combustion. Decayed wood and decaying animal or vegetable matter may form phosphori of this character; as is seen in light-wood, old pickle-barrels, and the bones of dead animals in certain conditions. The diamond, after long exposure to sunshine, flashes brilliantly in the dark by means of light previously absorbed; snow absorbs the sun's rays during the day, and renders the night less dark by gradually parting with them again when the sun is withdrawn:—several artificial as well as natural combinations of matter display this power in a high degree, and are thence called *solar phosphori*. Mere agitation of the particles of many substances occasions an elimination of light: thus, the friction or the sudden breaking of many crystalline minerals gives rise to bright flashes; as when loaf-sugar is broken in a dark place. Light also accompanies many electrical, magnetic, and galvanic experiments, and also many chemical changes in the structure of bodies. It is also *secreted* by peculiar organs in many living animals and plants: thus, certain plants—as the marigold, the tuberose, and the nasturtium—sometimes emit flashes from their flowers on a warm, quiet, summer evening; the fire-fly secretes light fitfully, and the glow-worm more steadily, near the tail; a few lantern-flies will enable one to read by the radiance of their beaks. Myriads of soft-bodied animals of the ocean produce

sides of any body, because no light incident upon such bodies can ever fall upon the second surface with an obliquity sufficient to be reflected and returned again to the first surface.

798. *Refraction through Prisms and Lenses.*—After ascertaining the index of refraction for any transparent body, it is easy to ascertain the direction of any ray of light after refraction. Let A B, Fig. 242, be a ray of light incident upon a curved surface at B: let C be the centre of curvature, and M N a tangent to the surface at B, lying in the same plane with A B, and C. Raise upon the point B, the line B D, perpendicular to M N, and also in the same plane. Then D B will be perpendicular to the surface at B, and from it and the sine of the angle of incidence A B D, we can find the angle of refraction and the course of the ray after entering the transparent body, by the method laid down in paragraph 790. In a similar manner, we may find the course of any given ray in passing out of the curved body into a rarer medium, whenever we know the index of refraction and the situation of the centre of curvature. If D B be produced, it will necessarily pass through C; for C B is a radius of the curvature at B, and all radii are perpendicular to the curvature at the point of intersection, and, therefore, to a tangent at that point; but, B, C, and D are all in the same plane; therefore B C and D C must be in the same straight line. With these explanations, you will be able to understand the following rapid sketch of the effect of prisms and lenses on the course of light.

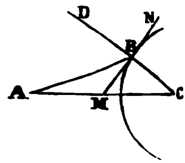

Fig. 242.

799. Any transparent body by means of which light may be collected, dispersed, or guided to the eye, may be called a *lens;* though the term is generally confined to bodies with curved surfaces. Lenses are usually made of glass or rock crystal (quartz). They are of various forms, chiefly the following: 1. The *prism,* seen in section at A, Fig. 243; 2. The *plane lens,* B; 3. The *spherical lens,* C; 4. The *double convex lens,* D; 5. The *plano-convex lens,* E; 6. The *double concave lens,* F; 7. The *plano-concave lens,* G; 8. The *meniscus,* H, in which one side is convex and the other concave, the radius of curvature for the concavity being the greater; 9. The *concavo-convex lens,* I, like the meniscus, except that the radius of curvature for the convexity is the greater. A line passing through the middle of any curved

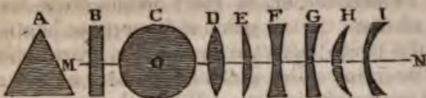

Fig. 243.

lens, so that its direction is perpendicular to both surfaces; as M N, Fig. 243, is called the *axis* of the lens. The sphere has an infinite number of axes; for every diameter fulfils the definitions. All other curved lenses have but one axis.

800. If parallel rays of light fall upon a spherical lens, they will converge to a focus after refraction, and this focus will be within or without the sphere, according to the index of refraction for the substance of which the lens is formed. Let M N, Fig. 244, represent such a lens, and A D, B E, C G, parallel rays incident on it. B E, falling perpendicularly on the surface at E, will pass on along the axis of the lens to *e*, without

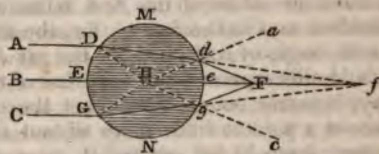

Fig. 244.

refraction. Here it will again fall perpendicularly on the surface, and will pass out of the lens without refraction, towards F and *f*. But all other parallel rays, such as A D, C G, will be bent towards the axis by refraction on entering the lens, because they will be refracted towards the respective perpendiculars D H, G H. If the lens be of glass, the refracted rays A D and C G will arrive at *d* and *g*, and if the medium were to continue uniform, they would meet the axis at *f*, which is very nearly the virtual focus for all such rays while still remaining within the lens: but the rays A D *d*, C G *g*, &c., pass out of the lens at *d* and *g*, and are therefore refracted from the corresponding perpendiculars H *a*, H *c*, and tend still more towards the axis: they thus reach and cross at or very near F, which is therefore the real focus of the lens for parallel rays. When the rays of incident light *converge*, it is evident that F must approach the lens, lessening the focal distance, H F; but when the rays are divergent, F must recede and lengthen the focal distance. If the principal focus F be considered as a point of divergence for luminous rays, then F *d*, F *e*, F *g* will represent incident rays, and the twice refracted rays D A, E B,

28 *

G C will be parallel, or, in other words, their focus will be infinitely distant. If the point of divergence be still nearer to the lens, the twice refracted rays will continue divergent.

801. The greater the index of refraction, the nearer the focus will approach the lens. When the index is equal to 2, as in zircon, the focus will be found at the surface of the sphere itself, at *e*, and if the index be greater than two, as in the diamond, the singly refracted rays will meet and cross each other somewhere between H and *e*, within the sphere.

802. A double convex lens is usually formed of equal portions of the opposite surfaces of spheres of the same radius or curvature: thus, in the sphere M N, Fig. 244, if you were to remove by a vertical section, a slice or layer of glass from M to N, and were then to bring together the opposite segments of the sphere, you would convert it into a double convex lens: but this would not change in any degree the amount or nature of the first refraction produced upon the incident rays in the figure: for, the angle H D *d* would still be the angle of refraction for the ray A D, and therefore D *d* would still represent the direction of the refracted ray. This ray, it is true, would then meet the opposite refracting surface at a point a little more distant from the axis B *f*, and hence it would fall somewhat more obliquely upon the second surface of the lens: thus: the angle of the second refraction, *a d* F, would be sufficiently increased to bring the ray to the same focus as before.

803. The principal difference, then, between the action of a double convex and a spherical lens consists in the latter having an infinite number of axes, and the former but one. The effect of this circumstance will be seen hereafter. When rays fall *directly*, parallel to the axis, (R, R, R, Fig. 245), upon a double convex lens (L, L), they are refracted to the principal focus of parallel rays (F); but if their incidence be oblique, they will be refracted to a focus placed at a greater or less distance from the former in proportion to the obliquity.

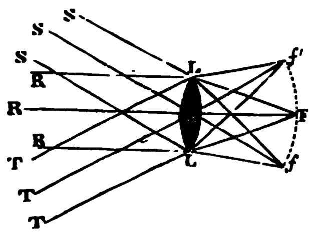

Fig. 245.

804. All rays falling obliquely upon any lens must be distorted by refraction; and when they emerge again from the lens, their position in space must be modified by the thick-

ness of the lens; for, although a ray twice refracted by passing through opposite parallel faces of any medium, emerges in a direction parallel to that of its incidence (788), its line of direction, when produced backward, will not coincide with its previous course. Thus; if part of a straight mark, drawn on paper, be viewed through a plate of glass, while the remainder of the mark continues visible beyond the edge of the glass, the mark will appear broken into two detached fragments, and the distance between the fragments will be determined by the thickness of the glass. The same kind of distortion necessarily occurs when the rays fall on curved surfaces; but, as allowances for this circumstance are apt to confuse the mind of the elementary student at first, it is customary, in speaking of the theory of lenses, to neglect this *aberration*, and consider these instruments as devoid of thickness, in mere elementary explanations.

805. Bearing this in mind, let L L, Fig. 245, represent a double convex lens. The parallel rays R, R, R, incident in a direction parallel to the axis R F, will be refracted to a focus at F. If the lens be of equal convexity on either side, and C be a point equidistant from all corresponding parts of the convex surfaces, this point is called the centre of the lens, and the focal distance C F will be about equal to the radius of curvature of either surface, when the lens is of glass, with an index of refraction of 1·5. If the parallel rays S, S, S, and T, T, T, fall obliquely upon L L, they will be refracted to the corresponding foci f and f', at the same distance from the centre C as in the former case.

806. This figure shows the power of convex lenses in concentrating light. The sun is so distant from the earth, that its rays may be considered as parallel, and when they fall on a convex lens, they are all concentrated upon the principal focus (782), together with the heat that accompanies them; and thus the lens acts as a burning glass.

807. In the double convex, as in the spherical lens, converging incident rays are brought to a focus nearer to the lens than the principal focus and diverging rays to a more distant focus. All that has been said, then, under the head of spherical lenses, on the subject of the position of foci, whether principal or secondary, real or virtual (800), applies equally to the double convex lens.

808. The plano-convex lens differs from the former chiefly in having a focal distance twice as great.

809. The double concave lens must necessarily produce effects exactly contrary to those of the double convex lens,

because the direction of the surface, in relation to that of incident rays, is exactly reversed: but the double convex lens concentrates parallel incident rays to a focus: therefore, a double concave lens must diffuse parallel incident rays by causing them to diverge from a corresponding *virtual* focus. Let L L, Fig. 246, represent a double concave lens; R, R, R, incident parallel rays, and F C the focal distance of a double convex lens of the same curvature. Then the rays, after being twice refracted, will diverge to *r*, *r*, *r*, and F will be the virtual focus of those rays. This will explain the reason why the eyeglass of a pair of concave spectacles, when held in the sunshine, near a wall or screen, casts thereon a deep shadow, surrounded by a very bright circle of the refracted rays. This circle of bright light often inflames the eyelids of those who are obliged to wear such glasses.

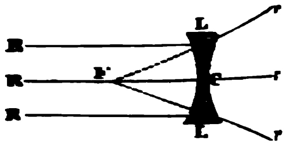

Fig. 246

810. *Images formed by Lenses.*—After what has been said of the effects of different lenses on the direction of the rays of light, a single illustration will be sufficient to explain the manner in which certain lenses produce images of objects, and may be employed to diminish or enlarge their apparent size. Let M N, Fig. 247, represent an object placed behind the double convex lens L L. It is plain that all the rays emanating from M, in the direction of the lens, such as M L, M L, M C, will meet in a focus, and cross each other at *m*; and will therefore paint the image of the part of the object marked M at this spot. For similar reasons, all the rays passing from N to the lens, will meet and cross at *n*, and rays from any intermediate part of the object M N will be concentrated upon a corresponding part of the space *m n*; which will present an *inverted* image of M N. The focus *m* for the rays emanating from M, will be found somewhere in the line of the ray M C *m*, and the focus *n* of the rays

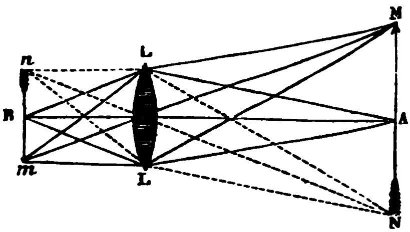

Fig. 247.

rom N will be found somewhere in the line of the ray N C *n*. 'he image will therefore be inverted, and its dimensions in ength and breadth will be to those of the object as the disance from C to *m n* is to the distance from C to M N. Such eciprocal foci as M and *m*, or N and *n*, are called conjugate foci, and their respective distances from the centre C are always reciprocally or inversely proportional.

811. The rays meeting at any spot on the surface of the image *m n*, become divergent after crossing each other, and spread out in the same manner that they would do if the image were a substantial object; and hence an eye placed at a suitable distance beyond *m n*, will actually see the image as if it were a real object suspended in the air. It will even appear much brighter than M N, because all the light emanating from the latter towards the eye, except the small portion absorbed by the lens, will appear to originate from the smaller space *m n*.

812. The smaller the radius of curvature of the lens, the nearer will *m n* approach the lens, and hence the smaller will be the image. But the larger the lens, the greater will be the brightness of the image, if the radius of curvature be fixed.

813. A faint twilight image is visible at *m n*, from every direction, for reasons already explained (784): but if smoke, ground glass, or any other translucent screen be interposed at *m n*, the light diffused therefrom will render the image distinctly visible in all directions.

814. The effect of such a lens in magnifying objects may be apparent or real. As the image and the object are always found at the conjugate foci (810), if *m n* be an object, M N will be its image:—thus, the same lens will give an image either larger or smaller than the object, according to the distance at which the latter is placed. But the apparent size of an object is determined by its distance from the eye of an observer; and, as the image itself may be employed as an object (811), if we approach very near to it, it will appear very large. The human eye perceives objects with the greatest distinctness at the distance of about six inches. Let us, then, suppose that the focal distance C A, Fig. 247, is thirty feet, and that C B is ten feet—M N being an object and *m n* its image. The latter will be diminished to one-third the length and breadth of the former, but, to an eye placed about six inches from *m n*, this image will appear about sixty times longer and broader than it would if placed at the distance B A = 30 feet. It will therefore appear twenty times

larger than M N appears to the naked eye, when viewed from the same point. On the contrary, if m n be the object, and M N the image, the former will be actually magnified three times, and if an eye placed about six inches from the image, the object will appear to be enlarged 18 times.

[illegible] A single lens with a moderate principal focal distance [illegible] tube, would form a simple refracting telescope [illegible] for astronomical purposes, as a single concave mirror would form a simple reflecting telescope, if it were not necessary for the observer to stand between the object and the image, in this case, so as to interfere with the light. Telescopes for terrestrial objects have usually at least two lenses, in order to produce *upright* images of objects [illegible].

[illegible] The human eye contains a lens which operates like that represented in Fig. 247, and produces inverted images of external things upon the back part of the eye. This will be better understood by reference to Fig. 248, which rudely represents a section of the eye.

[illegible] The eye is a hollow, somewhat spherical organ, formed of several membranes, of which the outer one, S, S, Fig. 248, is called the *sclerotic coat*. It is thick, white, and gristly—in some animals even bony. The optic nerve, O, enters it towards the back part, and spreads out into the delicate membrane called the *retina*, which lines the greater part of the sclerotic coat, and is protected by other membranes which need not be mentioned here. The sclerotic coat is wanting at the front part of the eye, and its place is supplied by a slightly protruding transparent cap of horn,

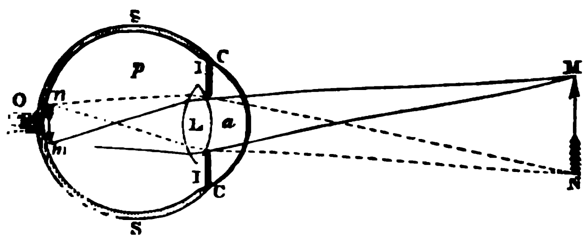

Fig. 248.

called the *cornea*. The cavity of the eye is full of transparent membranous sacs, containing an equally transparent fluid called the *aqueous* and *vitreous humours*. It is par-

tially divided into two chambers, *a* and *p*, by a circular curtain, I I, of many colours, called the *iris*, which is deficient or forms a round hole at its centre, towards *a*, called the *pupil*, through which light is admitted to the back part of the organ. Immediately behind the pupil is a hard, horny, very transparent double convex lens, L. With this explanation, and a reference to Fig. 247, you will perceive how inverted images of visible objects are formed on the back part of the eye. This mechanism is essentially the same with that of the common *camera obscura*.

818. The nearer an object approaches towards the eye, the farther off from the lens will be the spot where its image could be formed by the rays which emanate from it; and hence the eye requires and possesses a capacity of spontaneous adaptation to different focal distances; so that the image may always fall exactly on the back of the posterior chamber. This is effected in great degree by the pressure of certain muscles which surround the organ; and which render the cornea more or less projecting, or vary, slightly, the position of the lens. Persons with good sight can adapt the eye to all focal distances, from that fitted for observing the fixed stars, to that required for clear vision at the distance of six inches. Short-sighted persons have the cornea too protuberant, so as to refract the rays too much before they reach the lens, and thus cause the image to be formed before the light reaches the back of the eye. In old age, on the contrary, the cornea becomes flattened too much, the rays are not sufficiently refracted before reaching the lens, and the light falls on the back of the eye before the image is formed. These defects are tolerably well corrected by the use of concave spectacles for short-sighted people, and convex glasses for the aged.

819. The great divergence of the rays emanating from objects placed at the distance of less than six inches from the eye,—which removes their conjugate focus entirely beyond the retina—alone prevents us from seeing such objects distinctly.

820. If, then, we can so bend the diverging rays from such an object, as to cause them to enter the eye in parallel directions, we can examine it even at the distance of the tenth part of an inch. Now, this may be done by placing the object in the principal focus of a convex lens; for then all the rays passing from any spot on the object through the lens to the eye will be parallel (800), and the object will then be seen as bodies are seen at an immense distance, but of the

... whole object were within ... this case, the object ... inches to the focal ... one-tenth of an inch ...

... used independently to examine ... constitutes *a simple microscope* ... magnify the image of a neighbouring ... lens. The two lenses form a com... When ... used to magnify the image ... by the lens or *object-glass* of a ... lenses form the *astronomical* ... the upright image in the ... lenses form a *terre*... When applied to the image ... concave mirror (815), the ... *telescope*; and if used to ... object formed by a con... 249—the apparatus becomes a *re*... This subject will be made clearer by ... rays of light through the follow... represents an astronomical telescope, ... lens with a long focal ... *eye-glass*, has a short focal distance.

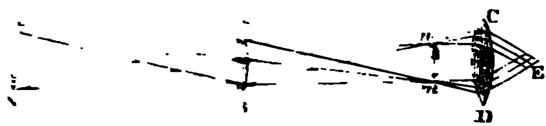

Fig. 249.

... represent a heavenly body, and the ... to exclude unnecessary light, ... will be so refracted as to produce ... the conjugate focus within the ... rays from heavenly bodies may ... therefore their conjugate focus ... principal focus of A B. The ... its principal focus coincides ... image ... and therefore all the rays ... from the image to this lens emerge from it in parallel lines (820), and reach the eye at E, in the manner of a simple microscope acting upon the image.

822. Fig. 250 represents a terrestrial telescope, or spy-

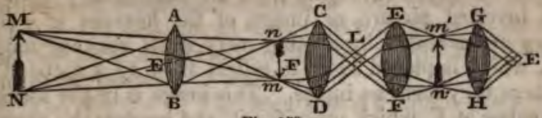

Fig. 250.

glass; A B, the object-glass, being fixed at the extremity of a tube, and the other lenses being secured in another smaller tube, sliding freely within the opposite extremity of the large one; so that C D, E F, and G H, are kept constantly in the same relative position, but may be made to approach towards, and recede from, the object-glass, at pleasure.

823. This instrument operates like the astronomical telescope as far as the point L, where an eye would receive an inverted image of the object, as in Fig. 249: but as M N, in this case, is placed at a moderate distance from the object-glass, the rays received from it are divergent rays, and their conjugate focus, at which the image *m' n'* is placed, must vary with the distance of the object. In order to use the instrument for objects at any given distance, the three remaining lenses, with their tubes, must be made to slide back or forth along the larger tube, until the image *m n* is placed exactly in the principal focus of C D, when the eye at E will obtain a clear view of the object, in the following manner. The parallel rays from C D are received by E F, and are so refracted as to find their foci at *m' n'*, where they form another and an upright image of M N, which is magnified and transmitted to the eye at E, in parallel rays, by the eye-glass, G H.

824. Reflecting telescopes are formed in various ways. Fig. 251 represents that of Newton. In this instrument, the ap-

Fig. 251.

parently parallel rays from the heavenly body, M N, are received into a tube, and fall upon a concave mirror, A B, the principal focus of which is at *n m*. Were there nothing to

arrest the rays converging from the mirror, they would form an inverted picture, or image, of the heavens at *n m*; but *they are arrested* by another very small concave mirror C, D, which is placed so as to reflect them to a focus at *n' m'*, where they form an image. This image is in the focus of an eyeglass at E, which magnifies it, and renders the visual rays parallel, as in the other instruments.

825. *Spherical Aberration.*—It has been already mentioned that the foci of mirrors with spherical surfaces are not true foci. This results from the form of the surface, and the equality of the angles of incidence and reflection (775). But the surfaces of most lenses are also spherical, and the sines of the angles of incidence and reflection have always a fixed ratio (790). Therefore the rays which fall upon the surface of a common lens are not all refracted to a true focus. The variation in the foci of different rays is called their *spherical aberration.*

826. Let L L, Fig. 252, represent a plano-convex lens, of which A F is the axis. The parallel incident rays, R L, R L, near the edge of the lens, will be refracted to a focus at *f*, while the similar rays, R′ L′, R′ L′, adjoining the axis, will be refracted to a focus at F. If, then, the light be arrested by a screen at F, the foci of the successive circles of rays from the centre to the edge of the lens will extend along the line *f* F, which therefore measures the *longitudinal spherical aberration:* and the circles of rays incident upon various parts of the lens, after crossing each other at their respective foci, will spread and illuminate the whole space, *f* G H; so that the line G H measures the *lateral spherical aberration.* Hence the light about the foci of spherically convex lenses is confused, and cannot form perfectly correct images. The appearance of the image of the sun projected

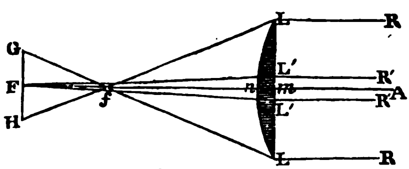

Fig. 252.

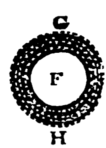

Fig. 253.

by the lens L L is seen in Fig. 253, where the central part about F is strongly illuminated, but is surrounded by a halo of scattered rays as far as the circle G H.

827. Lenses with different degrees of curvature produce

various degrees of spherical aberration; and by choosing the best form, and rendering the lens very thin, or by using the central part only, we obtain figures sufficiently accurate for most practical purposes.

828. You observe in Fig. 252, that the rays towards the circumference of a lens having one or both surfaces spherical, are too strongly refracted to assist in forming a correct image at F. If, then, we could form such a lens of a substance gradually decreasing in density from the centre towards the edge, in due proportion to the increasing obliquity of the surface, such a lens would have no spherical aberration. This cannot be done by art; but the lens of the human eye is actually constructed on this principle.

CHROMATICS, OR THE DECOMPOSITION OF LIGHT.

829. Chromatics is a subdivision of optics which treats of the formation of colours. It is, perhaps, rather a branch of Chemistry than of Natural Philosophy, but it produces phenomena which compel us to notice it in works on the latter science.

830. *Of the Spectrum.*—Hitherto we have spoken of light as if it were a simple substance, and its particles simple atoms; but we must now take it to pieces, and show that its particles are molecules composed of many atoms; or otherwise, that it is a mixture of several different fluids, rather than a simple one.

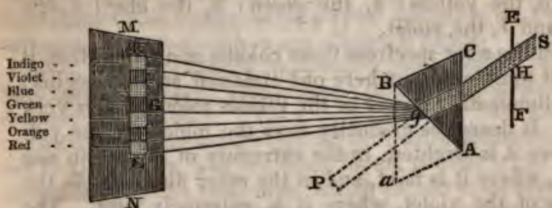

Fig. 254.

831. Let S, Fig. 254, represent a small beam of sunshine passing through a hole, H, in a shutter, E F, into a dark room, in such a direction that, if continued, it would pursue the route, S P. Let this beam be received upon the face, C A, of a transparent triangular prism, B A C, at such an angle as will cause it to emerge after two refractions, at g, in the direction g G. We should then expect to see a round

spot of sunshine of the ordinary colour, projected by the beam upon a white screen at M N; but this is not the case. An oblong narrow image of the sun will be seen, stretching all the way from K to L: and this image will present the eye with seven different colours, appearing in the order printed behind the screen, beginning with red light, which, being less refracted, forms the bottom of the image, and terminating with violet light, which, being most strongly refracted, forms its summit. This image is called the *solar spectrum*. Beams of other kinds of mixed light also present such spectral images, varying in colour with the colour of the beam itself; but if a round hole be made in the screen opposite the middle portion of either of the spectral colours, so as to allow rays of that colour only to pass into another dark space, those rays, if transmitted through another prism, will be affected in a manner consistent with the common laws of refraction, and if received upon a screen, will produce a round spot of the same colour.

832. According to the hypothesis of radiation, these facts go to show that common, or white light, is composed of various rays, capable of producing different sensations of colour, and hence, that it is *heterogeneous*, or composed of several kinds of light; having different degrees of *refrangibility*. White light, when thus *decomposed*, appears to contain seven kinds of luminous rays of *homogeneons light*, or light incapable of further decomposition, having increasing degrees of refrangibility, in the following order: 1, the red; 2, the orange; 3, the yellow; 4, the green; 5, the blue; 6, the indigo; and 7, the violet.

833. In the solar spectrum these colours so overlap, that it is difficult to determine where one ends and another begins; and the illuminating power of the various colours differs very greatly. It decreases gradually from the middle of the yellow, where it is brightest, to the extremity of the red in one direction, where it is faint, and in the other direction, to the extremity of the violet, where it is extremely faint. The spaces occupied by the different colours also vary. Newton taught that each of these coloured pencils of rays constitutes a distinct kind of homogeneous light; but others reduce the number of simple colours to three; because, according to Brewster, even the red colour contains some yellow and a trace of blue; the orange can be produced by mixing the yellow and red with a very little blue; the yellow contains a little red and a little blue; the green seems to be chiefly a mixture of yellow and blue, with a very little red;

the blue, so called, appears to contain some yellow and a trace of red; the indigo is judged to be a blue, with less yellow, and scarcely a trace of red. If you could spread the *red light* of the spectrum over the blank space marked R, Fig. 255, from M to N; *yellow light*, overlapping the former throughout the space marked Y; and *blue light*, over the space B, overlapping both the former; and if you could then concentrate all these lights on the oblong shaded space below M N, you would have precisely the arrangement of colours represented in Fig. 254. If all the light of the spectrum be collected, and made to fall upon one spot, sunshine is reproduced.

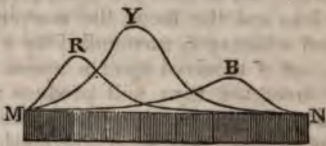

Fig. 255.

834. This decomposition and recomposition takes place whenever an oblique beam of light passes through any transparent body; for the separation of the colours begins at the first refracting surface, and would continue after the second refraction, were it not that, if the surfaces are parallel, the two refractions are equal and in opposite directions (788), and thus destroy each other's effect. In order, then, that light should be permanently decomposed by a refracting body, the surfaces must be placed obliquely towards each other. You will now understand why glass and gems, cut into figures with many faces, present iridescent or rainbow-coloured images of objects seen through them.

835. Light appears to be attended by, or united with certain *invisible* rays. These rays are also subject to various degrees of refraction. They seem to be of two kinds: 1, calorific or heating rays, which are unequally diffused throughout the spectrum, and are even found beyond it, at its red extremity: 2, chemical rays, which extend even beyond the violet extremity. The latter produces those changes in the colour or nature of animate and inanimate substances which are effected by exposure to light. To these, some writers add magnetic rays; but their existence is doubtful.

836. As the rays of light which fall upon different parts of a spectrum have different indices of refraction, it follows that no common lens can produce an accurately-coloured image of any object; for the violet rays composing part of every pencil of light, being more refrangible than the red rays in the same pencil, will come to a focus at a point nearer

to the lens than the red rays. Hence arises a peculiar aberration called *chromatic aberration*, which is totally independent of the spherical aberration.

837. If the light of the sun, passing through a common convex lens, be received upon a white screen placed between the lens and the focus, the converging rays will produce a round white spot, surrounded by a red circle, like a penumbra; but if received upon a screen placed beyond the focus, the diverging rays will produce a round spot, surrounded by a violet circle: because, while converging, the less refrangible red rays form the outside of the cone, but after crossing at the focus, the more refrangible violet rays take the exterior position. Chromatic aberration produces much embarrassment in the construction of optical instruments: but since it has been discovered that different kinds of matter having the same *mean* index of refraction *disperse* the various coloured rays through different distances, it has been found possible to construct compound lenses composed of such parts that the *dispersive power* of one part compensates that of the other, and brings rays of all colours to the same focus. Lenses of this kind are called *achromatic lenses*.

838. The rainbow is a chromatic phenomenon, seen only when the light of the sun or moon (very rarely the latter) falls on descending rain or spray, in such a manner as to reflect rays decomposed by refraction to the eye of an observer standing with his back to the source of light.

839. Two rainbows are often seen at the same moment—the one enclosing the other. Let these be represented by the dotted lines in Fig. 256. Let R R, &c., be parallel rays of sunlight falling upon the descending raindrops E, F, G, H. The two lowermost rays will be refracted by the drops E, F, and, striking upon the posterior portions of these spheres, will be partly reflected, and striking obliquely upon the lower surface of the drops, will be again refracted—the red or least refrangible rays in the direction from F to O, and the violet or most refrangible rays, in the direction from E to O, so as to reach the eye of an observer

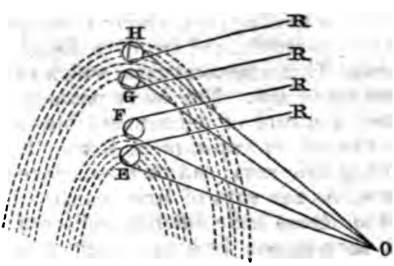

Fig. 256.

stationed at O. Hence, a spectrum having all the seven prismatic colours, will be seen stretching from F to E; the violet rays being undermost.

840. As the form of this spectrum depends upon the angle of incidence of the white sun or moonlight upon the surfaces of innumerable spheres, and as spherical lenses have an infinity of axes, the light will reach the eye in the same manner from all parts of a circle of drops at equal angular distances from the point directly opposite the sun; and hence the spectrum has the form of a bow resting at either extremity on the earth; and it would appear as a complete circle, were it not that the earth arrests the drops that should render it complete. Entire rainbows are frequently seen in the spray of water-falls, where we can look directly from the sun upon an entire circle of drops at a proper angular distance from the central point.

841. A rainbow formed by two refractions and one reflection, is called a primary rainbow. A second bow may be formed by two reflections and two refractions. Thus; the rays incident upon the drops G and H, Fig. 256, towards the lower parts of these spheres, are so refracted as to cause a small portion of the light to be twice reflected within the drop, as represented in the figure, and finally, to emerge in such a direction as to reach the eye: but the twice refracted rays here cross the corresponding incident rays; so that that which is most refracted—the violet—reaches the eye from the uppermost drop, and that which is least refracted, from the lowermost: the colours of this spectrum are therefore reversed. This is called the secondary rainbow. It is twice as broad as the primary, but much fainter; because the greater part of the incident light escapes at each reflection within the drop.

DOUBLE REFRACTION AND POLARIZATION.

842. These subjects constitute two of the most curious branches of optical study, but they are too difficult of explanation and study to be treated of in this little work, and we must be contented, at present, with little more than definitions of the terms, so that you may comprehend their meaning when met with in other works.

843. *Double Refraction.*—Hitherto, in treating of dioptric phenomena, we have spoken only of the passage of light through media of which the structure or the arrangement of particles is similar in every part, and in all directions. Of this class are the gases, fluids, glass slowly and regularly

cooled, crystals whose primitive forms are the cube, the regular octahedron or the rhomboidal dodecahedron. Under all ordinary circumstances, if of uniform or regular density, such bodies reflect and refract light according to the laws already explained. But by almost all other bodies—such as transparent animal or vegetable substances, crystals having other primitive forms than those already mentioned, glass irregularly cooled, &c.,—a single pencil of incident light is always divided into two detached pencils forming, an angle with each other which varies with the nature and condition of the substance. This angle is sometimes great and at others invisibly small, so as to be detected only by certain changes which the division impresses on the transmitted light.

844. Procure a rhomb of Iceland spar, smooth, clear, and at least an inch in length, Fig. 257. Place it over a black line M N, drawn on paper, as in the figure. Then, on looking upon the upper surface of the rhomb, in the direction R r, we may probably see the line doubled or separated into two lines, M N and m n. If not—turn the rhomb slowly round, keeping the same side constantly applied to the paper, and the line will soon appear separated into two; one of which remains stationary, while the other recedes from it during the first fourth of a revolution, and returns to it on the completion of half a revolution. On the completion of an entire revolution, the same appearances will be produced on the opposite side of the stationary line M N. If a round dot be formed at O, instead of a line, we shall see two dots instead of one, as at O and E; and while O remains stationary, E will appear to revolve in a circle around it, when the crystal is turned as before.

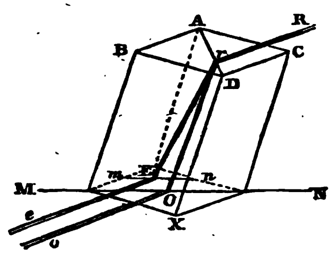

Fig. 257.

845. To explain this, let R r represent a pencil of light incident at r. It will be refracted by the surface into the two pencils r O and r E, which, being again refracted at the second surface, will severally take the directions O o and E e, parallel to each other and to the incident ray R r. The ray R r has therefore been *doubly refracted* by the first surface.

846. *Polarization of Light.*—It is found that when a pen-

cil of light has been doubly refracted, each of the two resulting pencils has acquired certain peculiar properties. Thus; when light in its ordinary state falls obliquely upon a transparent body, it is always refracted; but light that has been doubly refracted, when it falls upon a transparent body with a certain degree of obliquity, *is wholly reflected*, as if its particles were long and narrow, so as to enter easily in some positions, and not in others. Moreover, the properties of the two pencils formed by double refraction are apparently opposite to each other in character, so that one may be reflected under the same circumstances in which the other will be refracted. These, and a host of other interesting phenomena of a kindred nature, have led to the hypothesis that the rays of light are composed of atoms possessing opposite polarity, and that each molecule is composed of two atoms adhering together, like two magnets having their opposite poles placed near together. These polarized atoms are supposed to be separated by double refractions.

CHAPTER IX.

ELECTRICITY.

847. When certain substances, such as glass or resin, are rubbed with certain other substances, such as silk or fur, they are found to attract or repel light bodies at sensible distances. If a glass tube be rubbed with dry flannel, it will attract particles of dust, small pieces of paper, or a suspended thread placed near it; and these things will either adhere for a time, or they will fly off with force after momentary contact.

848. Substances which display this power, on being subjected to friction, are termed *electrics;* and those which, under ordinary circumstances, do not, *non-electrics.* These, however, are relative terms; for no known substance is either a perfect electric or a perfect non-electric.

849. The agent producing these attractions and repulsions forms no material part of the body which displays them; for it may be detached and conveyed from place to place, without losing its properties; yet it is imponderable. It is called *electricity*, and was proved to be identical with lightning by Dr. Franklin, who drew it from the clouds by means of a

kite and string. While the string was dry, no signs of electricity were seen; but when wet with rain, sparks of lightning, like those drawn from the ear of a cat when stroked by the hand, were seen to pass from an iron key to the doctor's knuckle when presented near it. These sparks were attended by a snapping noise, which was really mimic thunder on a very small scale.

850. This experiment shows that some things, such as dry cord, are *non-conductors* or bad conductors of electricity; while others, such as wet cord and iron, are conductors of this agent. But neither the conducting nor the non-conducting power has ever been found perfect in any substance. It has been found that all electrics are non-conductors, and all non-electrics are conductors of electricity. Electric or non-conducting bodies *adhere* when attracted in the manner described in paragraph 847; but non-electric or conducting bodies are repelled after momentary contact.

851. Certain instruments are contrived for the purpose of detecting the presence of electricity, and others, for measuring its attractive and repulsive force: the former instruments are sometimes called *electroscopes*, and both are included under the general term *electrometers*.

852. A ball of pith, which is a conductor, suspended by a fine silk fibre, which is a non-conductor and is therefore said to *insulate* the pith, forms the simplest of electrometers. When presented to a body *excited* or *charged* with electricity, the pith-ball is attracted, receives a portion of the agent by its conducting power, and is then instantly repelled: thus proving that while electricity attracts other bodies, it repels its own molecules with force sufficient to drive asunder ponderable bodies when in the same electrical condition.

853. The ball of the common pith-ball electrometer is usually suspended by means of a stiff thread of shell-lac from one extremity of a rod of glass, resin, or some other non-conductor, on the other extremity of which there is a conducting cap, usually of metal, with which the pith-ball hangs in contact. If this metallic cap be placed in contact with any body charged with electricity, both cap and ball will receive their share of the charge, and will repel each other. The degree of the repulsion is proportional to the intensity of the charge, and is measured by means of a scale marked on a quadrant of ivory (also a non-conductor), which is secured to the insulating rod; and the instrument then acts in a manner resembling the bent lever balance, Fig. 131 (p. 149).

854. If a piece of resin and another of glass be each excited

by a piece of fur, either will attract, charge, and then repel the ball of the simple electrometer; but when charged by the resin, the ball will be attracted with unusual force by the excited glass, and when charged by the glass it will be similarly attracted by the excited resin. This clearly shows, that when excited by friction with the same substance, the glass and the resin are brought into opposite electrical states or conditions. This may be still more clearly shown by means of the gold-leaf electrometer, Fig. 258, consisting of a glass tube, with a metallic or other conducting base, A, from which two narrow slips of gold-leaf or tin-foil, B, B, run up the inside of the tube to some distance, being secured to the glass by paste. This tube is surmounted by a metallic cap, and from within its centre, depend two narrow slips of gold-leaf, D, D, placed side by side when unelectrified, and opposite to the strips, B, B. Upon the cap, is placed another metallic disc, E, called a *condensing-plate*, designed to receive electricity, and communicate it to the dependent leaves of gold, which, with the cap and condensing-plate, are insulated by the glass.

Fig. 258.

855. It is easy to take away a portion of the electricity from any part of an electrified body by the following means: Take a small piece of gilt paper, or other light, flat, conducting substance, and secure it upon one end of a needle of shell-lac, which is perhaps the best of non-conductors. On touching an *electrified* or *electrized* body at any part of its surface with this *proof-plane*, the proof-plane will receive a charge of electricity, equal in intensity to that of the body at the point of contact, which cannot be carried off from it by the non-conducting needle, and therefore remains upon it when it is removed. With a proof-plane thus charged, touch the condensing-plate, E, Fig. 258, and the gold leaves will instantly separate, because the electricity of the plane will be dispersed over the whole of the insulated plate, the cap and leaves; beyond which it is prevented from escaping, by the non-conducting tube of glass on which they rest. If, however, the proof-plane be large, and the charge of considerable intensity, the repulsion of the similarly electrified leaves, together with the attraction of each leaf for the corresponding unelectrified slips of metal, B, B, will cause the leaves to diverge until they touch the slips; when, instantly, the electricity will be diffused through the metallic base,

is called *the striking distance*; and it is much greater near the extremities of a long insulated conductor than in the neighbourhood of its centre. This fact can be tested by charging a proof-plane successively from different parts of any conductor, and ascertaining the corresponding intensities of the fluid by means of the electrometer. Here you have a complete explanation of the influence of the lightning-rod in protecting buildings. When electricity escapes from a pointed projection, it steals off very rapidly, without noise or with a slight hissing sound, and reaches bodies at a great distance.

862. When any two different substances are rubbed together, or even placed in contact, their electric condition is usually changed from the natural state. If either or both of the substances have conducting power, and be insulated, it may be shown that the natural electricity of these substances is decomposed by the mere proximity of different kinds of matter: but this will be better understood after you are made acquainted with the doctrine of *electrical induction*.

863. When any insulated conducting body in the natural electrical condition is brought near another body in a different electric state, the fluid natural to the former is decomposed by their mutual re-action, to an extent proportional to their difference of condition.

864. Let A, Fig. 259, be a conductor, insulated upon a glass rod and highly charged with positive electricity; and let B be a moveable long conductor of the same material, insulated in a similar manner and surmounted by a number of detached strings carrying at each extremity a ball of pith, to serve as so many electrometers. If B be placed a little beyond the striking distance of A, all the pith-balls will diverge, except one pair placed near the middle of B; thus showing that B is electrified throughout, except at one place near the middle. The divergence of the pith-balls will be greater as they are placed nearer to either extremity of B. To prove that these results are not a consequence of the passage of any electricity from A to B, let a non-conducting plate be placed near these conductors, and the same effects will still appear. If we now test the nature of the electricity of B, at the extremity next to A, by means of a proof-plane and a gold-leaf electrometer, Fig. 258, we shall find that

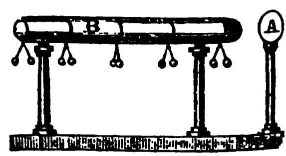

Fig. 259.

spheres of any conducting substance, each insulated upon a non-conducting handle, and made to fit exactly to the surface of a metallic or other conducting sphere. Then insulate the sphere and electrify it. On applying the two unelectrified hemispherical caps for a moment, and then removing them, the electrometer will show that all the electricity has left the sphere, and is concentrated on the surface of the hemispheres.

859. If a small hole be bored in a conducting body, and the body be then slightly charged with electricity, the proof-plane carefully introduced into the orifice will display no signs of the presence of electricity when applied to the condensing-plate of the electrometer; but when the proof-plane touches any part of *the external surface* of the electrified conductor, it instantly acquires a charge, and will cause the leaves of the electrometer to diverge.

860. The only bodies over which electricity can diffuse itself uniformly, are those of spherical form; because this is the only figure upon which molecules, mutually repelling each other can remain at rest in the form of a layer of uniform thickness. In an elongated, or angular body, the repulsion of the fluid adhering to the middle portions of the surface of the mass cannot be effectually resisted by the repulsion of the fluid on the more projecting portions, except by an accumulation of molecules about those parts. Now, the only reason why the electricity does not escape from a charged body, when placed upon a non-conducting support, while it is surrounded by the atmosphere, is this: air is an electric, or non-conductor; and hence the electricity cannot escape rapidly, until it has sufficient intensity to overcome by its repulsion the resistance of this barrier. In a vacuum, electricity cannot be retained. The tendency to escape must therefore be greater upon the prominent parts of a conductor than in other places; and if the electrified body be furnished with a very sharp projection, like the point of a lightning-rod, the tendency may be increased almost without limit. This is equally the case, whether the electricity be positive or negative. Hence the presence of a pointed projection renders it impossible to charge a body with any considerable amount of the fluid.

861. When electricity escapes from one charged conductor to another not in contact with it, and if this escape take place from a rounded or flat surface, a considerable quantity of fluid bursts through the air at once, producing a spark and a report. The distance through which any spark is able to pass

is called *the striking distance;* and it is much greater near the extremities of a long insulated conductor than in the neighbourhood of its centre. This fact can be tested by charging a proof-plane successively from different parts of any conductor, and ascertaining the corresponding intensities of the fluid by means of the electrometer. Here you have a complete explanation of the influence of the lightning-rod in protecting buildings. When electricity escapes from a pointed projection, it steals off very rapidly, without noise or with a slight hissing sound, and reaches bodies at a great distance.

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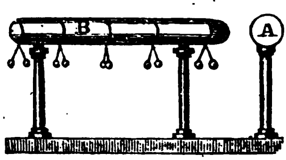

Fig. 259.

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the electricity of this extremity is negative; but if the electricity of the opposite extremity of B be tested in the same manner, it will be found to be positive, like that of the conductor A. If we apply the proof-plane near the centre of B, it will produce no sensible effect upon the gold leaves; showing that this part of the conductor remains in the natural state.

865. Remove the conductor B to a distance from A, and all the balls will collapse; thus proving that B has received no additional electricity, but has merely suffered a disturbance of its natural quantity by being brought near the charged body A.

866. Replace B, and the effects will reappear. Then bring the finger (the human body being a conductor) within striking distance of the positively electrified extremity of B. A spark of positive electricity will then be drawn off, and the divergence of all the pith-balls will be very much diminished. If B be then once more removed to a distance from A, it will be found negatively electrified throughout.

867. But if B be brought completely into contact with A, the electric charge of the latter will be proportionally distributed over both conductors, and they will both display the same kind of electricity as if the two conductors were one at every point.

868. Were we to test the electric condition of the charged conductor A, when B, in the natural state, is brought near to it, we should find that the former has undergone the same changes of condition, to a certain extent; that is; the positive electricity is accumulated in larger amount on the side farthest from the conductor B; while, opposite the nearest part of B, it is either slightly positive, neutral or negative, according to the form and distances of the two conductors.

869. If A be a non-conducting body, its charge is prevented from moving over the surface, and therefore cannot change its condition in the manner just described: these changes will therefore be confined to the conducting body B, and will appear even greater in degree.

870. If the charge of A be negative instead of positive, exactly the same changes will be observed, but the order of the series of results will be reversed, that which was before negative becoming positive, and that which was positive becoming negative.

871. All these experiments appear to show, that when two conducting bodies containing different amounts of electricity approach each other, the surplus electricity of either

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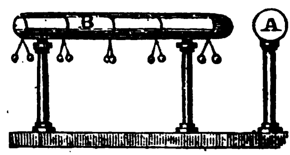

Fig. 259.

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871. All these experiments appear to show, that when two conducting bodies containing different amounts of electricity approach each other, the surplus electricity of either

kind in one of the conductors, repels the similar fluid in the other, to as great a distance as possible, and is repelled by it with equal force: thus, when either of the bodies is in the natural state, the mixture of the two fluids, which neutralize each other in that state, is decomposed by repulsion; and if the two bodies be insulated, both fluids will display their properties at different points on the surface of each.

872. Bodies so circumstanced must necessarily attract each other: for, as electric attraction varies inversely as the square of the distance, the attraction of the surplus fluid in A, Fig. 259, for the fluid of the opposite kind collected at the nearer end of B, must be greater than its repulsion for the similar fluid accumulated at the more distant part of B.

873. Bodies, of which the electric state is disturbed by the proximity of other bodies in a different state, are said to be electrified by *induction*. While a thunder-cloud charged with negative electricity is passing, the surface of the earth beneath it is rendered positive by induction, until, in some instances, the hairs of animals become electrometers and stand on end. The tips of masts, lightning-rods, fence-posts, &c., may then become luminous from the escape of positive electricity toward the cloud. If the cloud be low and the electric intensity great, an upward flash—the most common form of lightning—may occur, producing terrible destruction. Life may be destroyed by lightning, even when no flash is communicated from the earth to the cloud: for, if one cloud discharge itself into another, the negative electricity driven by induction from the surface of the earth beneath instantly returns, producing what is called a *side-shock*, sometimes so powerful as to kill persons who happen to be near large and partially insulated masses of conducting mat ter. Such accidents, however, are fortunately very rare.

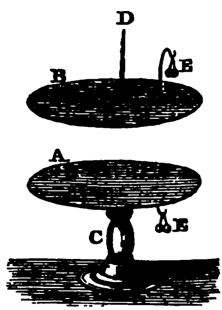

Fig. 260.

874. The attraction of the two electrical fluids for each other is such, that when they are accumulated separately on opposite sides of a non-conductor, this attraction prevents either of them from displaying its energy in full force upon surrounding objects. Thus, let A and B, Fig. 260, represent two widely separated metallic discs, the one insulated upon a glass rod, C, and the other upon a silken

cord, D; each being furnished with a pith-ball electrometer, E. Let these plates be charged separately with opposite electricities, and the balls of both electrometers will diverge. If B be now lowered gradually towards A, this divergence will continually decrease, as though the charges of the discs were diminished; but this is disproved by the divergence being gradually restored on separating the discs once more.

875. The diminished divergence of the electrometers on the approach of the two charged discs towards each other, is solely owing to the strong attractions of the molecules of the opposite fluids for each other, which, varying inversely as the square of the distance, must be four times as great when the interval between the discs is reduced one-half. Electricity thus prevented from acting freely on surrounding bodies by its own attractions, is said to be *disguised.*

876. When the discs are brought within striking distance of each other, a discharge takes place from one to the other, both the electricities are neutralized, and the electrometers collapse. This neutralization also occurs when a conducting-wire or *discharging-rod* is placed in contact with one of the discs, and is then brought near the other disc. The discharging-rod is usually made of a metallic wire, surmounted at its extremities by metallic balls, A, B, Fig. 261, and insulated upon a glass or dry-wood handle, as at F.

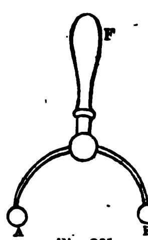

Fig. 261.

877. If glass, or any other solid electric, be substituted for the air between the discs, Fig. 260, the same effects will be observed; and, even if a very thin plate of glass be used, the strength of attraction, when the discs are heavily charged, may overcome the cohesion of the electric; and a discharge will then take place through its substance, generally breaking it in pieces.

878. If we charge only one of the discs in the foregoing experiment—A, for instance—the other will be electrified by induction; and if the fluid repelled by the charge of A be drawn off from the opposite side of B by the finger or any other conductor, new charges may be communicated to A for a long time, before the electrometer appended to it will diverge to its full extent.

879. Moist air is a tolerably good conductor, and therefore the success of this and other experiments performed in

the air depends upon the dryness of the atmosphere. The density of the air also renders it more powerful as a non-conductor. Under the exhausted receiver of an air-pump, electricity diffuses itself by repulsion through the free space, and collects upon the inner surface of the glass. If the expanded fingers be then moved about the receiver near the outside surface, streams of light like an aurora borealis will be seen playing through the void, and following the motions of the hand.

880. No aerial insulation can be complete; for the particles of air in immediate proximity to an electrified body acquire by degrees the same electric condition, and are repelled, while others more distant are in turn attracted, and receive their charge. This is the cause of the cool breeze which seems to issue from any pointed projection of an electrified conductor when the supply of electricity to this conductor is continued. Thus the air carries off the surplus electricity from bodies, and promotes its equilibrium by a process similar to the distribution of heat in fluids by circulation. This action is very slow in the neighbourhood of flat, or large rounded surfaces; but from projecting points and elongated bodies it is very rapid (861). When the air is thus electrified, it is expanded by the increased repulsion of its particles; and you are now prepared to comprehend the action of electrical machines, the Leyden vial, and the electrical battery.

881. *The Electrical Machine.*—The general appearance of electrical machines is known to almost every American child; but, for the purpose of explanation, we will take up that of Mr. Nairne, represented in Fig. 262, as it possesses some advantages for experimental purposes. C C is a cylinder of glass. It is supported and revolves upon two uprights, made of insulating materials—such as baked-wood thickly varnished. One extremity of the axle of the cylinder carries a small wheel, *w*. A larger wheel, W, is attached, by a central pivot, to the corresponding upright. It should be made of non-conducting materials, and should be pro-

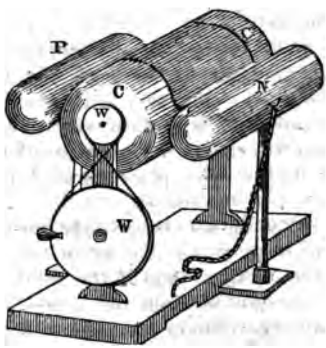

Fig. 262.

ided with a handle of the same character. These wheels are coupled by means of a cord, and enable us to cause the cylinder to revolve rapidly.

882. An insulated conductor, N, called the negative conductor, is supported by a glass rod fixed to a sliding panel at its base, by which it may be made to approach or recede from the cylinder. This conductor is provided with a long narrow rubber on the side next the cylinder, against which it is made to press by means of the sliding panel. Over the face of this rubber, where it touches the cylinder, is spread a thin narrow layer of *amalgam*, composed of tin, zinc, and mercury, made into a paste with lard, which very much increases the excitation of the glass. In the common machine, the conductor N is wanting, and the glass rod carries the rubber alone. To the face of the rubber, just above the line of amalgam, is attached a flap of silk, designed to encircle nearly all the upper half of the cylinder, and to prevent the air from dissipating the electricity collected on the glass by friction with the rubber. The mere contact between the cylinder and the rubber causes the partial decomposition of the natural electricity in the latter. The positive fluid is collected upon the glass, and is carried round by it; while the negative fluid remains in the conductor N and rubber, and will there cause an electrometer to diverge with negative electricity.

883. The continued excitement of the glass soon brings the intensity of its electricity to the point at which its attraction for the negative fluid in the conductor, N, puts a stop to the further decomposition, unless, by some means, we contrive to carry off the electricity accumulated upon the glass. For this purpose, another similar conductor, P, provided with pointed wires, projecting until they come very near the glass, is insulated upon another glass rod, attached to another sliding panel, on the opposite side of the cylinder. When thus arranged, if the cylinder be put in motion, the conductor P is immediately electrified by induction, and there is a tendency in the side next the cylinder to become charged negatively, while on the opposite side the positive fluid accumulates. But the positive electricity of the moving cylinder instantly flies off to the points on the conductor, P, and not only neutralizes the negative electricity produced there by induction, but continues to flow until the whole of this conductor becomes charged positively to such a degree of intensity, as to balance by its repulsion the fluid remaining on the cylinder.

884. If a finger of one hand be now presented to the conductor P within striking distance, a moderate spark may be drawn from it, followed by others still more feeble: for the supply of positive electric fluid in N is speedily exhausted. But let a metallic chain or other conducting substance be suspended from N to the stand supporting the machine, which is always covered with a conducting-plate of metal communicating with the earth, and instantly, P will commence giving powerful sparks to the finger—the intensity, and consequently the striking distance, being greatly increased. This is owing to the fact that N, now no longer insulated, is supplied from that great reservoir of natural electricity, the earth, with fresh supplies of the positive fluid, which continually re-establish the natural condition of N, and render the process of decomposition and the supply of positive electricity to the conductor P perpetual.

885. Let the chain be removed from N and suspended from P. The electric condition of the latter will now continue natural while the machine is in motion; because all the electricity received from the glass instantly passes off through the chain into the earth. But N will be rendered strongly negative, because the glass constantly demands from it fresh supplies of the positive fluid. If a finger be now brought within striking distance of N, a series of sparks will burst from the former, to supply the deficiency of positive fluid in the latter. Here, then, there appears to be a current of positive electricity produced, in which the excited glass draws the fluid from N, to deliver it to P, which transmits it to the earth, and this, sharing it with the person of the experimenter, his finger returns it to N. If the finger be made to touch N, all signs of electricity disappear from both conductors, and its presence will be perceived only on the surface of the glass; for, all that is delivered to P is then instantly returned to N.

886. If, while both conductors are insulated and the machine is turned by an assistant, the finger of one hand be presented near P, and a finger of the other near N, sparks will take place at the same moment from P to one finger, and from the other finger to N; and these sparks will produce a very curious sensation: but if the fingers touch the respective conductors, the transfer takes place without any sensible result.

887. If a cylinder of resin be substituted for the glass, and a rubber of flannel for the amalgam, the cylinder will abstract negative electricity from N, and all the other appearances will be reversed; the positive portions of the appara-

tus becoming negative, and the negative portions being rendered positive.

888. These phenomena are explained, on the hypothesis of the double fluid, by supposing that the machine establishes a double current; the positive fluid passing in one direction and the negative fluid in the other, and neither of them displaying visible effects, except where there is a break in the circle.

889. *Transmission of Electricity.*—The passage of electricity along conductors, or through non-conducting media, appears to occupy no appreciable time.

890. In passing through air or other obstacles, the fluid always endeavours to pass by the shortest possible route; so that, if two conducting routes be established between bodies in different electrical conditions, the fluid will travel by the shorter. Great resistance is offered to the passage of large quantities of electricity along narrow conductors; and if these be much bent, the fluid will sometimes leap through the air, from one part of the conductor to another, in preference to travelling round the curve: for this reason; lightning-rods, with dull points and extensive curves, not unfrequently cause the lightning to leap through the roof and side-wall of a house, from one part of the rod to another.

891. When sparks or flashes of lightning are long, the fluid appears to condense the air before it so powerfully as to be frequently turned off at an angle, or even to rebound momentarily from the reaction of the air upon it. In such cases, brushes of light often escape into the air, or become *dissipated* at the angular points. These two effects produce many of the most beautiful phenomena of thunder-storms, and of sparks drawn from long conductors attached to powerful electrical machines.

Fig. 263.

892. *Of the Leyden Vial.*—It has been explained that where a body charged with electricity of either kind is brought into proximity with another body charged with electricity of the opposite character, the mutual attraction of the two fluids disguises the effects of both (875). Now, let B, Fig. 263, be a glass or other electric bottle or vial, coated internally and externally with tinfoil or some other conducting matter to a considerable distance from

the bottom. If a conducting-rod communicating with the inner lining of this vessel be terminated by a rounded body, of the same nature, as represented at A, and if this ball be presented to the prime conductor of an electrical machine, P, Fig. 262, the inner surface of the vial will become charged with electricity of the same nature with that of the prime conductor. By induction, this electricity will decompose the natural electricity of the outer coating of the vial, drawing the fluid of opposite character towards the side next the vial, and repelling the fluid of its own nature from it, towards the outside of the external lining. If the external lining of the vial be connected with the earth by a good conductor, the repelled fluid will escape and disappear in the general reservoir (884); but the attraction of the one fluid, within the vial, for the opposite fluid accumulated by induction, without, will prevent either from displaying its properties unchecked in their full extent; the electrometer will be less influenced, and the striking distance will be very much diminished: hence, such a vial will bear a vastly greater charge of electricity than a common insulated conductor, before the fluids will meet and neutralize each other by breaking through the air or the intervening glass. If, however, the whole vial be insulated, as it is when suspended by a silk cord or placed on a bench supported upon glass feet, it will receive no higher charge than an ordinary conductor.

893. A vial thus prepared is called a Leyden vial, from the place of its invention. Plates of window glass, lined upon each side with tin-foil reaching to within a few inches of the edges, are frequently employed for the same purpose, and act like the stratum of air in the experiment with the two discs described in paragraph 874.

894. *The Electric Battery.*—By connecting together by conducting wires the rods of several of these vials, and uniting their external coatings in a similar manner, we cause them all to act in concert; and thus, we obtain any desired quantity of electricity, in such a state that we may use it in our experiments with perfect facility. Such an arrangement is called an *electrical battery.*

895. Leyden vials and batteries are readily discharged by means of the discharging-rod, as represented in Fig. 263. When we wish to test the effects of large quantities of electricity upon any substance, we make the subject of experiment a part of the circle of connexion between the inner and outer coating of a jar or battery, at the moment of discharge: *thus,* if we place a card between one of the balls of the dis-

charging-rod and the side of the jar, and then discharge the latter in the usual manner, the card will be found perforated by the electricity. If a large battery be employed, and fine metallic wire be substituted for the card, it may be heated red-hot, melted, dispersed, or even forced into the pores of glass by the heating and explosive power of the fluid.

896. When the communication between the surfaces is made by means of the human body, whether it be by a single individual or by many persons touching each other, a severe shock is felt; but it is confined to those parts of the body which lie in the shortest route between the inner and outer coating. Electricity thus applied has been useful in disease; and its application is often confined to a single limb or part of a limb, by means of conducting chains or rods, which may be so applied as to bring the part into the direct route of the circle of connexion between the surfaces.

897. The changes of form, constitution, temperature, &c., continually going on among ponderable bodies, are constantly producing changes in their electric condition, and render the study of electricity at once deeply interesting and abstruse. Thus there is reason to believe that the machinery of all animals and vegetable bodies possesses the power of decomposing electricity in certain parts of their frame, and some animals have actual batteries constructed within them, by means of which they can benumb or even kill their prey. The electric eel and the torpedo are fishes endowed with this power, and when in full vigour they can give shocks dangerous to the life of a swimmer.

CHAPTER X.

GALVANISM.

898. The term *Galvanism* has been given to a branch of the science of Eectricity, which treats of the effects of the two electric fluids when set in motion through conductors, so as to form currents, by means of the simple contact of the different metals. Its details belong rather to Chemistry than to Natural Philosophy, but its connexion with Magnetism renders it necessary to say a few words upon the subject here.

899. It had long been known that a strong electric spark, or the shock of a Leyden vial, would produce pain in the nerves

and contractions in the muscles of a living animal, and it was also known that when two pieces of different metals were placed, the one on the upper and the other on the lower surface of the tongue, when damp, the edges of the two metals being brought into contact, there was produced a very peculiar taste; but the connexion of these two facts with electricity was not perceived until Professor Galvani, of Bologna, discovered that when a piece of metal is applied to the naked muscles of the leg of a frog recently killed and skinned, while a piece of some different metal is applied to the principal motor nerve of the limb, and when a metallic wire is made to connect the two plates, the leg will be thrown into convulsions. This effect was then attributed to a change in the electric condition of the metals when connected by a conductor: and the taste above mentioned was explained on the some principles.

900. Modern discovery has shown that the muscles of all animals may be excited by electricity in any form, if properly applied soon after death; the bodies of the inferior and cold-blooded animals retaining this susceptibility for the longest time; and further investigation has proved the agency of electricity in the experiments of galvanism.

901. When insulated discs of two different metals are placed in contact and again separated, it is found that one of them has acquired positive and the other negative electricity to a sufficient extent to affect a very delicate electrometer. It is found that the more oxidizable of the two metals will always be charged positively. Thus, zinc will render copper negative by contact, while even copper becomes positively charged when in contact with gold or silver. The intensity of this action is much increased by subjecting the metals to some agent which tends to produce oxidation—such as a very dilute acid: and even when the acid is capable of uniting with either of the metals separately, its energy will be wholly exerted upon one of them when they are brought into contact, either directly or by means of conducting-wires.

Fig. 264.

902. The nature of what is called a simple galvanic circle may be made intelligible by Fig. 264, in which Z represents a zinc plate, and C, a copper-plate, both partially immersed in a very weak mixture of sulphuric acid and water. These plates being placed in contact at their upper edge, a current of electricity immediately commences, and

continues until they are separated; the positive fluid running from C to Z, and back through the acid to C again, while the negative fluid flows in the opposite direction from Z to C, and back through the acid to Z. The existence of this current is readily shown, upon breaking the circle at any point: thus, while placed as in the figure, the acid will rapidly corrode the zinc, but will leave the copper bright; but if the summits of the plates be separated, both will be corroded. This arrest of chemical action in one plate, while it is proceeding in the other, is a proof of the agency of the opposite electricities, but this proof being chemical, we cannot discuss it here.

903. If a metallic or other conducting-wire be soldered to the summit of each of the plates, the circle may be completed even when Z and C are ever so widely separated, merely by bringing these wires into contact. If the tongue be inserted between the positive wire coming from the zinc and the negative wire coming from the copper, *the galvanic taste* (899) is instantly recognised.

904. Let the two plates, with their wires connected, be dipped into the acid mixture contained in different tumblers, and both will be corroded; but if a moistened thread be carried from the mixture in one tumbler to the mixture in the other, the galvanic circle becomes complete, and the corrosion of the copper ceases, while that of the zinc is increased.

905. By arranging many pairs of galvanic plates in a pile, separating the successive pairs by pieces of moistened pasteboard, it is found that the intensity of the electric or galvanic current is increased; each pair communicating its own electricity or galvanism to the next successor, together with all that it has received from its predecessors. Such an arrangement is called *the voltaic pile*, from its inventor, Professor Volta, of Pavia. It must always have a zinc, or positive plate at one extremity, and a copper, or negative plate at the other. The wires used to complete the circuit, or convey the fluids for purposes of experiment, are connected with these opposite extremities of the pile, of which the zinc end is called *the positive pole*, and the copper end *the negative pole*.

906. The acid used in some of the foregoing experiments only increases the current, but is not essential to its production; for M. De Luc constructed two dry piles composed of pairs of very small circular plates, of two different kinds of metallic foil, separated only by circular pieces of dry paper; which he included, to the number of many thousands, in two glass tubes. These tubes were fixed upright upon a metallic

stand, one of them with the positive and the other with the negative pole uppermost. These columns were surmounted by two little bells, and between them was suspended a long and delicate needle, with a ball on its summit and a weight to counterpoise it below, playing like a metronome upon a pivot near its middle point, and insulated by the glass tubes containing the piles. So great was the electric action of these dry piles, that the ball of the metronome was alternately attracted, charged and repelled by each bell in turn, so as to keep up a perpetual ringing, as the electric fluid was conveyed from one part of the *galvanic circle* to the other. In good weather, sparks could be seen to pass between the ball and bell at each vibration.

907. By soldering together plates of zinc and copper, or other suitable dissimilar metals, and connecting the positive plate of each pair with the negative plate of the succeeding pair, we can produce a galvanic battery of any required power, by simply increasing the number and size of the plates, and plunging them into a succession of separate non-conducting vessels containing weak acid mixture. Fig. 265 represents a convenient mode of arrangement for this purpose. A B represents a wooden beam, from which the plates are seen suspended, a piece of metal being extended from each copper plate to the succeeding zinc one, and the whole series prepared to be partially immersed into the corresponding compartments of the wooden trough T, which is divided into chambers by partitions of glass. The trough, when in use, contains the acid mixture, and the positive and negative wires are attached to the opposite poles, P P, of the series. Any number of such troughs or of the piles of Volta may be made to act as a single battery, by making a connexion between the negative pole of one and the positive pole of another. There seems to be no compound body in nature that may not be decomposed, melted, or exploded

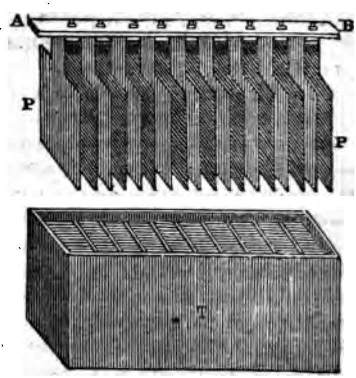

Fig. 265.

y such combinations of galvanic plates. Sparks of consi-erable length and shocks fatal to life may be produced by hem.

908. As the galvanic current produces many results not usually observed in the action of common electricity, it has been supposed, by some, that the galvanic fluid is a compound of caloric and electricity. Be this as it may, it appears that the ordinary electrical effects of the battery increase with the number of the plates, while the heating power increases with their size, and some chemical results appear to depend upon certain relations between their size and number.

909. The most splendid lights ever witnessed by man, are produced by the action of the galvanic current upon different kinds of matter interposed between the wires in the route of the galvanic circle. Thus, the Drummond light is produced by throwing the current upon lime: but any further remarks upon this subject would involve us in questions belonging to the science of chemistry.

CHAPTER XI.

MAGNETISM.

910. The most common phenomena produced by magnetism are too familiar to demand more than a simple announcement. It is well known that iron and steel are capable, from some cause, of assuming polarity; and it has been already stated that mere position appears to confer this property under certain circumstances. When left free to move upon a pivot, one pole of a piece of magnetized steel usually tends to the north, and the other to the south; whence these poles are called the north and south poles of the magnet.

911. This direction is varied by many circumstances, some regular and others apparently accidental. The proximity of iron and certain other metals produces an accidental variation of the bar or needle; nor does the presence of any intervening matter prevent this effect. In northern or southern latitudes, the corresponding pole of the needle of a compass is drawn downwards towards some point within the substance of the earth; and if we would preserve it in the horizontal position, we must load the other extremity with a

suitable weight. This downward tendency is called the *dip* of the needle. It is observed, that the point of the heavens toward which the north pole of a horizontal magnetic needle tends, seems to vibrate a little to the east and west of the true north direction: and as the dip varies also in different years, it is certain that the magnetic poles of the earth change their places according to some hidden law; and it is probable that they revolve regularly in a small circle, round some fixed point within this range of *the cyclic variation.*

912. The position of the needle also undergoes minute changes of position, which are repeated in various degrees every twenty-four hours, called *the diurnal variation.*

913. Again: The needle is *agitated*, or *disturbed*, during storms—particularly thunder-storms—earthquakes, the *aurora borealis*, and certain other meteors.

914. *Influence of Electricity on the Needle.*—Magnetism may be conferred upon iron, or destroyed when pre-existing in it, by the electric shock; or the poles of a magnet may be suddenly reversed by the same means, according to circumstances. These various effects were formerly explained upon the hypothesis that there existed in iron and a few other substances, a peculiar compound imponderable fluid, capable of being decomposed into two fluids of opposite properties; as in the case of electricity. This compound fluid was called the magnetic fluid; and those of which it was supposed to be constituted, were termed *austral* and *boreal.*

915. *Universality of Magnetism.*—Modern discovery has proved the existence of traces of magnetic attraction and repulsion in many substances, besides iron and the iron ore called the load-stone, which is chiefly composed of oxide of iron. It has been detected strongly in the metal called nickel, more feebly in cobalt, and weakly in brass, the emerald, the ruby, the garnet, glass, chalk, and many other mineral as well as organic substances; and it is now believed to be a general property of matter.

916. *Electro-magnetic Phenomena.*—In 1819, Professor Oersted, a Swedish philosopher, ascertained that electric currents have the power of conferring magnetism upon bodies susceptible of such impressions. Mr. Faraday, of London, has since succeeded in obtaining an electric spark from the magnet, and has thus reduced this branch of science to a department of the science of electricity. The following facts have now been ascertained.

917. When a metallic, or other electrical conducting-wire —called a *connecting-wire*—forms part of the galvanic cir-

cle, and when it is placed above the magnetic needle, at a short distance, and in a position parallel to the needle, that end of the needle which points towards the negative galvanic pole will tend towards the west, even though the connecting-wire may not be *directly* over the needle.

918. If the connecting-wire be in the same horizontal plane with the needle, there will be no lateral change of position in the magnet, but it will dip.

919. If the connecting-wire be on the east side of the magnet, that end of the needle which lies next the negative galvanic pole of the circle will dip; and when it is placed on the west side, the magnetic pole next the positive galvanic pole, will dip. If the connecting-wire be placed below the needle, the parallelism being still preserved, the effect will be precisely the reverse of that produced when it is above the needle.

920. If a piece of steel, not magnetized, be placed in a position parallel to the connecting-wire of a battery when in action, the side next the wire will assume, temporarily, one kind of magnetism, and the other side will display the opposite kind: but if the direction of the wire be at right angles with that of the steel, the latter becomes a permanent magnet, with the usual poles at its opposite extremities. If a coil of any kind of wire, covered with silk or cotton thread, be made in the form of a helix, like that of a suspender spring, and if this helix be made part of the connecting-wire, any piece of *steel* insulated and placed longitudinally within the coil will soon be converted into a permanent magnet, in consequence of the action of the electric current upon it. By connecting the ends of the wire with the opposite poles of the battery, which is called *changing*, or *reversing the poles*, the poles of the magnet will also be reversed. If a coil of this kind be wound round a magnetic needle, exceedingly slight quantities of electricity transmitted through the wire will cause variations of the needle, which therefore becomes a delicate electroscope or electrometer. It is used to test the electricity generated by the contact of metal.

921. If such an *electro-magnetic helix* be formed around a piece of *soft iron*, and a current from a battery be made to pass through it, the iron instantly becomes powerfully magnetic. If the connexion with the poles of the galvanic battery be reversed, those of the magnet will be reversed also; and thus the same extremity of the iron may be made alternately to attract and repel any other body susceptible of magnetic impression. The magnetism thus conferred depends

entirely upon the current of electricity; for it ceases instantly, if the galvanic circuit passing through the helix be broken in any part. Temporary magnets have been prepared in this way, which were capable of raising, by attraction, weights of more than 2,000 pounds; and this force can be destroyed at any moment by simply disconnecting one of the wires from the pole of the battery.

922. As either pole of a magnet attracts the opposite, and repels the similar pole of another magnet, you perceive at once that *electro-magnetism* furnishes us with considerable motive power when a galvanic current from a battery is passing about a piece of soft iron, in the neighbourhood of any common magnet; for by merely reversing the poles of the temporary magnet, we interchange attraction and repulsion from the same point at will. If the common magnet were made capable of revolving on an axis, so that its poles should come alternately into close proximity with one of the poles of the soft magnet at every half revolution, we should only have to change the character of the latter pole each time that either extremity of the moveable magnet arrived at this point, and we might thus create a circular motion of the common magnet, by causing its approaching pole to be attracted, and its retreating pole repelled at all times: thus creating a circular motive power, which, by the aid of the acquired momentum of a fly-wheel and the moving magnet itself, might be usefully applied to machinery. Applications of this principle have actually been made: but it has not been decided whether they can be economically employed.

923. The most wonderful applications of this agency of electrical currents to the daily purposes of life are dependent upon our power of creating and destroying powerful magnetic attraction at will, and instantaneously, in bars of soft iron, by means of insulated wires conveying the influence of the galvanic battery to any required distance. The explanation of this subject will require the aid of three suitable figures.

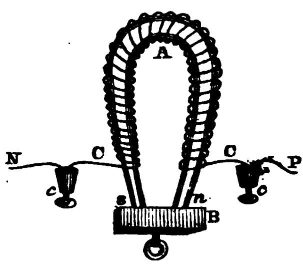

Fig. 266.

924. A, Fig. 266, represents a large bar of soft iron curved into the form of a horseshoe, in order to bring its opposite magnetic poles to within a convenient dis-

ance of each other. B, is a detached piece of iron, designed to be upheld by the attraction of A, when magnetized by a galvanic current. It is armed with a ring or hook, designed to support weights for testing the strength of the attraction, or to give attachment to various apparatus, when required. A long wire, C, C, generally of copper, surrounded by silk thread or otherwise insulated, is closely wound in the form of a helix around the bar A, commencing near the extremity *s*, and terminating near the opposite extremity, *n*. The ends of this wire, after completing the helix, are led off and made to dip into some mercury contained in the two little cups, *c*, *c*. The conducting-wire P, comes from the positive end or pole of a distant galvanic battery, and the conducting wire N, comes in a similar manner from the negative end or pole of the same battery.

925. When P and N are dipped into the mercury in their respective cups, the galvanic circle is completed by the pile, the wires, and the mercury; and thus a strong current of electricity or galvanic fluid is made to circulate around the bar A. This bar is then instantly converted into a powerful magnet, and B adheres to it with great force by the magnetic attraction. If, however, either of the wires, P or N, be raised for an instant, the circuit is broken, the current ceases, and A being no longer a magnet, B immediately falls. Upon recompleting the connexion, the same process is renewed at pleasure. You perceive, at once, how two such magnets acting alternately on opposite sides of an iron beam, would give us a reciprocal motion capable of ready application to machinery.

926. *Electro-magnetic Alarm-Bell.*—The apparatus just described has been, of late years, most wonderfully applied to the conveyance of messages. The electro-magnetic alarm-bell may be understood by reference to Fig. 267, in which the same letters have significance as in the preceding figure, though the magnet A is reversed, and firmly secured to a table. In this instrument, the detached iron, B,

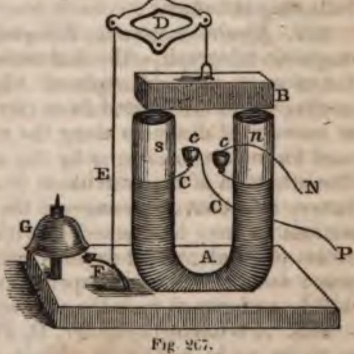

Fig. 267.

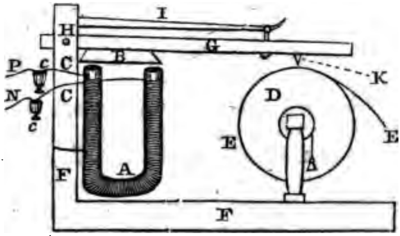

Fig. 268.

e first commu-
d to it by
or by the ac-
f the galva-
paratus itself,
y be thought
esirable. On
ylinder, there
rcular groove
derate depth;
er it plays or
e continuous sheet of paper, E E, on which the mes-
s received.

. A curved bar of iron, A, with its helix-wire, C, C,
s mercurial cups, *c c*, is supported, as in the alarm-bell,
it, upon a stout wooden frame F, F. A light wooden
r lever, G, having a little vertical play or motion about
t at H, bears, near its attachment, the usual detached
of iron, B, and is supported by a steel spring, I. A
projection, K, hangs directly over the groove in the
ler, to which its form is adapted. When the conduct-
ires, P, N, are brought into connexion with the battery
other end of the line of communication—the cylinder
its paper sheet being simultaneously set in motion—
A becomes a magnet, and forcibly attracts the cross-
B; thus drawing downward the lever G, and causing
ojection K to indent the paper into the groove upon the
e of the cylinder, producing a permanent raised mark
e opposite side of the sheet, resembling the raised cha-
s employed in the instruction of the blind. The mean-
f these characters is determined by their length; and
epends on the length of time that the writer at the sta-
eeps the galvanic circle complete at each dip of the
cting-wire in its cup, or at each contact of the wire
the pole of the battery.

CONCLUSION.

In bidding adieu to my young readers, I sincerely hope that those of them who have given close attention to the subject of this volume will find themselves prepared to comprehend the wonders of the physical world by which they are surrounded, to an extent which will amply repay them, in after life, for the labour required in studying the elements of one of the noblest of human sciences. Let them remember, however, that what is commonly called "an education," is intended to teach no more than how to begin to learn.

APPENDIX.

TABLE OF THE SPECIFIC GRAVITIES OF VARIOUS BODIES.

SOLIDS,

Compared with Water, at 32° Fahrenheit.

Agate,	2·590
Amber,	1·064
Barytes,	4·000 to 4·600
Fat Beef,	0·923
Butter,	0·942
Camphor,	0·988
India Rubber,	0·933
Coals,	1·020 to 1·300
Diamonds,	3·521 to 3·550
Glasses,	2·520 to 3·000
Indigo,	1·009
Ivory,	1·825
Lard,	0·947
Galena,	6·565 to 7·786
Limestone,	2·386 to 3·000
Marble,	2·560 to 2·716
Metals—Brass,	7·824 to 8·396
Copper,	8·900
Gold—cast,	19·258
hammered,	19·361
Iron—cast,	7·248
forged,	7·788
Lead,	11·352
Platina—forged,	20·336
wire,	21·042
plates,	22·069
Silver—	10·474
hammered,	10·510
Steel—soft,	7·833
tempered,	7·816
hardened,	7·854
Tin—	7·294
hardened,	7·299
Zinc,	6·200 to 7·191
Plumbago,	1·987 to 2·400
Rock Crystal,	2·581 to 2·888
Spermaceti,	0·943
Sugar,	1·606
Sulphur of Commerce,	1·900
Tallow,	1·941
Wax,	1·964
Wood—Apple,	0·793
Ash,	0·845
Beech,	0·852
Box,	0·912
Wood—Cedar,	0·596
Cherry,	0·715
Cork,	0·240
Ebony,	1·331
Elm,	0·671
Fir—male,	0·550
female,	0·498
Lignum Vitæ,	1·333
Mahogany,	1·063
Maple,	0·750
Oak-heart,	1·170
Pear,	0·766
Plum,	0·785
Poplar,	0·383
Walnut,	0·681
Willow,	0.585
Yew—Spanish,	0·807

LIQUIDS,

Compared with Water, at 32° Fahrenheit.

Alcohol—absolute,	0·797
of commerce,	0·835
Blood,	1·053
Ether—Muriatic,	0·729
Nitric,	0·908
Sulphuric,	0·632
Honey,	1·450
Mercury,	13·598
Oil—Cinnamon,	1.043
Linseed,	0·940
Olive,	0·915
Turpentine,	0·870
Whale,	0·923

GASES,

Compared with Atmospheric Air.

Ammoniacal,	0·590
Atmospheric Air,	1·000
Carbonic Acid,	1·527
Chlorine,	2·500
Exhilarating,	1·527
Hydriodic Acid,	4·340
Hydrogen,	0·069
Nitrous Acid,	2·638
Oxygen,	1·111

QUESTIONS.

CHAPTER. I.—PROPERTIES OF MATTER.

General Remarks, - - - - - - - - - - page 7

How does a child become acquainted with *space?* 2.

Define *the general and special properties of things?* 3.

Define *matter*, *impenetrability*, 4; *extension*, 5; *thing* and *body*—Why is not the universe called a body? 6, 7, 8.

Define *mobility*—Is it universal? 9. What constitutes relative rest? Define *inertia*, 10. Is matter *divisible?* 11; how far? 12.

Give examples of the effects of *gravity*, 13. Define gravity, 14. What is the term for the cause of gravity? 15.

How is it proved that all things on or near the earth gravitate towards one spot within it? 16. How is it proved that all parts of the earth possess the attraction of gravitation? 18. What law of gravity was proved by the torsion balance? What is *density?* 19.

Extension, - - - - - - - - - - - - page 14

Enumerate and define the general laws of matter, 20.

Explain the nature of a *point*, 23, 24. Of what is it a property? 25. Give examples of points, 26.

Explain the nature of a *line*, 27, 28. What is meant by *definite*, *indefinite*, and *produced* lines? 29, 30. Of what is the line a property? 30. What is a *straight line?*—what is a *definite straight line?*—what is a *curved line?* 32. What is a *curve?* 33. Give an example of a curve, and of its *law*, 34.

Define the word *law*, with examples, 35. Define the words *circle*, *circumference*, *radius* and *diameter*, 36. Describe the *ellipse*, with its *foci*, its law, and its *diameters*, 37, 38. What is an *orbit* of a planet? Name the planets in the order of their distance from the sun. Name them in the order of their sizes, 39. What is the *eccentricity* of an ellipse? What is said of the eccentricities of the primary planets and of comets? What of the position of the sun? How can we know the orbit of a comet? 40.

Define and explain the meaning of *superficies*, 41, 42. What is meant by a plane superficies? 43.

What is meant by a solid figure, or a *solid?* 45.

What are parallel lines and planes? 47, 48. Can a line be parallel to a plane? 48.

What is an angle? 49, 50. What is the *angular point?* How are

angles designated? 50. Does the greatness of an angle depend upon the length of the lines? 51. What is a *right angle*? What is the meaning of *perpendicular*? 52. What is an *acute angle*? What is an *obtuse angle*? 53. How are angles measured? 54, 55.

How are circles divided into *degrees*, *minutes*, &c.? 56. Explain how time is measured by degrees, 57. How many degrees are there in half a circle?—in one fourth of a circle?—and in a right angle? 58. What is the *chord of an arc*? What line in a circle is equal to the chord of 60°? How can we lay down angles on paper? 59, 60. How do you know when one plane is perpendicular to another? 61.

How many lines can enclose a space? How many straight lines? What is a *triangle*?—and a rectilineal triangle? How are curvilinear triangles named? 62. What is a *helix* and a *spiral*? Can they enclose space? 63. What is *angular velocity*? Explain its influence in forming various spirals, 64. What is a *solid angle*? 65.

Define the different kinds of triangles, 66, 67—and of *quadrangles*, 68—and of *polygons*, 69.

What is a *sphere*? What its law? 71. What is an *axis*? Describe the two kinds of *ellipsoids*. What are called poles? 72. How is the cone generated? 73. How the cylinder? 74. Describe the different *parallelopipeds*, 75, 76, 77. Describe the *prism*, 78—the *pyramid*, 79—and the regular *polyhedrons*, 80, 81.

What is said of the measurement of space? 82, 83. How are lines measured? 84?—how surfaces? 85. What is said of numbers?—what of the *square* and square-root of numbers? (*Note*, 85.) How are solids measured? 86.

Divisibility, - - - - - - - - page 38

What is said of the thinness of gold? 87; of the smallness of animals? 88; of the diffusion of odours, and blue vitriol when dissolved? 89. What proof have we that matter is not infinitely divisible? 90.

What are *atoms*? 90. How do mineralogists endeavour to ascertain the forms of atoms? 91, 92.

What is meant by the *primitive form* of a crystal, and how is it ascertained? What is *cleavage*? 93, 94. What is the primitive form of fluor spar? 94. Name the six primitive forms of crystals. Which of them are unchangeable? 95.

What is meant by *the form of an integrant molecule*? How many forms of integrant molecules are there? Name them, 96. What is said of the difference between *atoms* and *integrant molecules*? 97. What is *crystallography*? What is the probable form of atoms? How would you construct the different forms of molecules with such atoms? 98.

Attraction and Repulsion, - - - - - - - - page 43

What is said of the attraction of floating bodies at sea? What of the attraction of molecules? 99. What of the floating needle, of drops of water, of soap-bubbles, and of quicksilver? 100. What is the *attraction of cohesion*? 101. What is the office of cohesion? Give

examples of *adhesion*, 102; and of adhesion between solids and fluids, 103.

What is said of attraction in a tumbler? 104; between panes of glass, and in glass tubes? 105. What is the meaning of capillary attraction? 106. What is said of its general influence; of its effects on dry surfaces, on the floating needle, on spiders, and on mercury? 107. What influence has the narrowness of passages on capillary attraction? Give examples, 108. What determines the height of fluids in irregular capillary tubes? Give examples. Will water flow through very narrow holes? 109. What has capillary attraction to do with the life of plants and animals? 110. How does it affect floating bodies? 111, 112. Has it the same cause with other attractions? 113.

What proofs have we that *porosity* is a property of matter? 114. Give additional examples, 115, 116. Are bodies impenetrable?—are atoms?—are molecules? State proofs, 117.

What causes the repulsion of atoms and molecules? What is *heat?* What is *caloric?* 118. What are the two hypotheses of caloric? 118, 119, 120. What is meant by *imponderable matter?* 121. What proves that light is *reflected?* 122. What is meant by good and bad conductors of caloric? 124. What is the *radiation* of caloric? 125. Prove that light and caloric can be *absorbed*, 126, 127. Explain the law by which radiating light and caloric become diffused in space, 128, 129. What is *free* or *sensible caloric?* 130. Describe the *thermomer*, 131. What happens when water is heated around the bulb of a thermometer? What does it prove? 132, 133. What is *latent caloric?* 133. What becomes of steam when cooled below 212 degrees? What becomes of its latent caloric? 134. How is warmth conveyed from place to place by steam? 135. How does the freezing of water affect the thermometer? 136. What is said of the melting, boiling away, and freezing of solids and liquids? What are *gases?* 137, 138. On what do the solid, liquid, and gaseous states of matter depend? What would become of the world if heated or chilled too much? 139. Describe the effects of heating and cooling on the bulk of water. At what temperature does water freeze? At what temperature is its density greatest? 140.

How do you explain the changes of bulk in water and ice by temperature? Explain their effects on climate, 141. What forces generally determine the three states or conditions of matter? 142. Explain the *solid* state, 143; and the *fluid* state, 144; and the *liquid* state, 145; and the *aeriform* state. What is a gas? What, a vapour? 146.

What causes the *peculiar states* of matter? 147. Explain *hardness*, 148. Does it depend on density? 149. Explain *tenacity, friability*, 150; and *brittleness*, and the process of *annealing*, 151; and *fran-*

gibility. Describe Prince Rupert's drop, 152. Describe *mallea-bility*, 153; and *ductility*, 154; and *elasticity*, 156. Do elastic bodies rebound? 156. What happens when they are compressed? 157.

What is a magnet? What bodies are magnetic? 158. How can you make an artificial magnet? 159. Describe some of its effects, 160. What do they prove? What are called poles in magnets? Name the poles, 161. Can magnets polarize other bodies? Give an instance, 162. How can you make a needle permanently magnetic? 163. How do similar poles act on each other? How do contrary poles? 164. What is said of other kinds of polarity? State the general law, 165.

CHAPTER II.—Mechanics.

Prove that all *rest* is *relative*, 166. What is *absolute motion?* Do we know any thing of *absolute rest?* 168. What is said of *relative motion?* 168, 169. Give the first law of motion, with examples, 169. Prove that this is also a law of rest.

What is *velocity?* How is it measured? What is the unit of measure generally employed? 171. Prove that velocity is a measure of *force*, 172, 173. Is force measured by *absolute* or *relative* velocity? 174. What is *collision?* To what is it proportional? Give arithmetical illustrations, 175.

What is the difference between *resistance* and *force?* What is *inertia?* What is the difference between the inertia of rest and motion? What is the difference between action and reaction? 176. What regulates motion? 177.

What has *time* to do with motion, force and inertia? Give illustrations, 178. Give additional illustrations, 179, 180; and still more, 181, 182, 183.

Give examples of fluid resistance to motion, 184, 185. What law of velocity governs fluid resistance? 186.

What is *friction?* Give an example, 187. What is said of the laws of friction? 188. What of the cause of friction? 189. What of its effects on machinery? 190; on dragging bodies, on ropes and tissues? 191; on air and currents? 192; on the rapidity of rivers, on fertility, and on lakes? 193.

What has *mass* to do with velocity? 194. Define *momentum*. Give an arithmetical demonstration, 195. What have *weight* and *density* to do with the velocity of falling bodies? 196. Explain the experiment with a guinea and a feather, 197.

Explain the experiment with a sling, 198. What is *centrifugal force?* 199. What is *centripetal force?* What has it to do with the stars? 200. What is a *tangent?* What is the direction of centrifugal

force? 201. Give examples from the grindstone, rail-roads, steam-boats, stages, riders, skaters, fly-wheels, &c. 202. Explain the whirling-table, and form of the earth, 203. Give other examples, 204.

Composition and Resolution of Forces, - - - - - page 88

Explain the parallelogram of forces, 205. What do you understand by *resulting forces* and *resulting motions*? 206. Can we determine, by the motion of a body, what forces put it in motion? 207. How is the parallelogram of motion applied, when more than two forces act in the same plane upon a body? 208, 209. How, when three forces act in different planes? 210.

What is meant by *the composition of forces*? 211. What is said of forces acting at a right angle? 212. What, when they act at an obtuse angle? 213. What, when they act at an acute angle? 214.

Give geometrical demonstrations on the black-board of the several problems in *the resolution of forces*, from 215 to 217.

What portion of the velocity of moving bodies determines the force of their collision? Demonstrate this truth from the action of wind on sails, and water on paddle-wheels, &c. 218, 219. In what direction will an inelastic ball drive off another ball, not fixed, on which it strikes obliquely, and in what direction will it move itself, if it strike a ball that is immoveable? 220.

Constant Forces—Accelerated and Retarded Motion, - - page 95

Explain the difference between the effects of *constant* and *temporary* forces upon motion and velocity, with examples, 221, 222. What is said of the variation of gravity with distance? Give the law and examples. When may we consider it as a *uniform force*? 223. Give the law of the *accelerating force* of gravity, measured by *time*. 224, 225. How is the *accelerated motion* of a falling body measured by *distance*? Repeat and explain the series contained in the table, page 97—226, 227, 228, 229. State the conclusions drawn from this table, 229. Are the numbers in this table absolute or relative? To what do they apply? 230. Do the laws proved by the table apply to gravity alone? 231. How do you calculate the distance through which bodies will fall by gravity in any given time, at any given distance from the surface of the earth? How far do they fall in the first second, at London? 223; and at the equator? and at the poles? 224. How do you thence judge the height of precipices, &c.? How of the rate of sound? 234.

Explain the laws which govern bodies moving against a uniform retarding force, 235, 236. What is said of the action of gravity on bodies moving horizontally? 237.

What is the angular change of the direction of the gravity of the earth for each geographical mile? 238. Name the curve formed by *projectiles*. Explain this curve in horizontal projections—239; and in oblique upward projections, 240. What is said of projection directly upwards? 241. Give additional demonstrations of the

course of upward projectiles, 242. Demonstrate the curve in projections obliquely downward, 243. Describe the effects of gravity on fountains, &c., 244. What is said of the resistance of air to projectiles? 245. Describe Atwood's machine, 246, 247; and its application, 248.

How can gravity and centrifugal force produce a satellite to a planet? 249. Why cannot a projectile describe a spiral around a centre o. attraction? 250. What forces retain the planets in their orbits, and how? 251. Describe Kepler's law of equal spaces in equal times. Where is the common centre of the planetary revolutions? How is it proved that the orbits of all planets must be elliptical? What is said of comets? 252.

Of what use is the pendulum? 253. Demonstrate the resolution of the force of gravity on the inclined plane? 254. State the seven laws of constant forces acting on bodies on inclined planes, 255. Explain the law of descent along chords in a semicircle, 256. What is said of the descent of a series of inclined planes? 257. What of projection from them, and of cataracts? 258. Explain the law of descent along curves, 259. What is the law of ascent along curves? Explain the motion of the pendulum, 260. Does *weight* affect motion on inclined planes or the motion of pendula? 261. Explain and demonstrate its influence on pendula, 262, 263. Show the cause and nature of the *centre of oscillation,* 264, 265. What is called the *length of a pendulum?* 265. What effect has the distribution of the weight of a pendulum to do with its beat? 266. Why do the times of long and short vibrations differ? What effect has temperature on the beat? 267. What are *compensating pendula?* Describe one, 268. Describe the *metronome* and its uses, 269.

Describe the generation of a *cycloid,* 270. What are its chief properties? 271. What is said of the accelerating force on a cycloid? 272. Describe the *cycloidal pendulum,* 273.

By what law does the length of a pendulum affect its beat? 274. What length beats seconds? What length half seconds? What length triple seconds? 275. Explain the application of the pendulum to the measurement of heights, local attraction, and the figure of the earth, 276.

Of the Impact of Bodies. - - - - - - - - page 123.

Define *Impact,* 277. Explain its relations with *weight* and *velocity.* 278. Explain the law of the communication and arrest of momentum, with examples, 279.

Explain the effects of impact on momentum when bodies having equal and opposite momenta meet, 280; also, when the momenta differ, 281; also, when the velocities are equal but the weights differ, 282; also, when the momenta have the same direction, 283; also, when the bodies *impinge* obliquely? 284. Give arithmetical demonstrations of the foregoing questions, 285, 286. Give the two

rules for calculation, 287; and demonstrate on the black-board the geometrical illustration, 288. How do you estimate the effect of impact when one of the bodies is hard and immoveable, 289.

Give examples of the effects of impact modified by the peculiar properties of bodies, 290. Explain the experiment with a snow-ball, 291; that of two boys playing, 292; that of the anvil, 293; and that of the Waterloo bullet, 294.

State the effect of elasticity on impact, 295; give the illustrations with the hoop and the ivory ball, 295, 296; with the explanation, and the law deduced from them, 297. Explain the effect of the impact of two elastic bodies upon the momentum of each, 298. Describe the experiment with two elastic balls, 299. What is said of the impact of elastic bodies on hard bodies? 300. What of their impact on soft bodies? 301. Describe how the two elastic balls interchange velocities, 302. Describe and explain the several experiments with a series of ivory balls, 303, 304; also, that with a soft inelastic ball interposed, 305. Explain the effect of elasticity on the breaking of hard bodies, 306; and human bones, 307. State and explain the law of the reflection of elastic bodies, 308, 309.

Equilibrium and the centre of gravity, - - - page 137

What is the centre of gravity? How is it found? Why are bodies balanced when it is supported by suspension? 310, 311. State the two practical conclusions, 312. When will a body remain at rest when propped from below, in the direction of the centre of gravity, and why? 313, 314. When is the position of a gravitating body resting on a surface *stable?* Explain this by the inclined plane, 315; by dandies and sailors, 316; by the stowage of a wagon, and a ship, 317; by a ball rolling up hill, 318; by the experiment of supporting a board by loading it with a weight, 319; and by rope-dancers, 320.

Explain the equilibrium of a system of two bodies of equal weight, 321; and of unequal weight, 322, 323. Give an instance of *mechanical advantage*, 324. How do you measure distances of bodies from the centre of gravity of systems? 325. Explain the rule for determining equilibrium when the weights and the whole length of the system are known, 327. Also; when both weights and the distance of one of them is known, 328. Also; when the sum of the weights, the whole distance, and the centre are known, 329. Also; the rule for systems of many bodies ranged in a straight line, 330. What is said of the scale-beam? 331. What of the steel-yard? 332, 333. What of angular balances? 334. Describe the quadrant balance, 335. How do you find the centre of complex systems? 336. What is said of the centre of gravity of irregular bodies? 337. Where is the centre of gravity in the sphere, circular and elliptical tables, the cylinder and prisms? 338. What is said about it, in bodies ranged about plain polygonal

figures? 339, 340. Where is this centre in parallelopipeds? 341. Where is this centre in a line, or a space? 342.

What is meant by the *centre of inertia*? 343. Explain the effects on the motion of systems, by forces applied there, 343, 344; and by forces, applied at a distance therefrom, 345, 346. Round what point will a system revolve relatively, when struck obliquely? 347. Give the three laws governing the action of such forces, 348. Explain and demonstrate the *centre of spontaneous revolution*, 349, 350. Is this centre always within the system? 351. Demonstrate on the black-board the cycloidal motions of systems, 352. Give examples, from the motion of missiles, &c., 353; and from planetary bodies, 354.

Explain the necessity of the planetary revolutions, 335. Apply the same law to mundane affairs. Explain the experiment of the suspended poker, 357. What is said of pivots in machinery? 358.

Explain the *centre of percussion*, 358. What has it to do with the form of mauls and hammers? 360. And with the coupling of machinery? 361.

Of the Mechanical Powers and Simple Machines, - - page 162

What is the purpose of machinery? What is called *resistance*, and what, *power*, in machinery? 362. What is said of the direction of force in machinery? 363. Give examples. What is the purpose of *mechanical advantage*? Define and illustrate *the centre of action* in machinery. 364.

Define the general law of momentum in machinery. 365, 366. What is said of the application of this law? 367. Explain the law of *time* and *power* in machinery, 368. Illustrate it, 369.

What are the two simple elements of machinery? 370. Illustrate the nature and use of the common lever, 371. Also, of those levers called *wheels-and-axles*, 372. Also, of those called *pulleys*. What is a *block*? 373. Explain the nature of those inclined planes which are called *screws*, 375. Give examples. How is the screw often aided? 376. Explain the inclined planes called the wedge, 377. And its uses, 378. How many mechanical powers are there? Name them. How many are usually spoken of? Name them, 379. What is said of measuring pressure and momentum? (Note). 378.

What is the difference between the lever and the balance? What is said of the centre of action and the calculation of the mechanical advantage in levers? 380, 381.

Explain the nature and the law of equilibrium in levers of the first order, 383; and the second order, 384; and the third order, 385. Explain the laws of fulcral pressure in the three orders of levers, 386. Prove that this division into orders is purely artificial, 387. Explain the law of equilibrium on combined levers, 388.

Describe the nature and use of bent levers, 389. How do we calculate their mechanical action when the power and resistance are

parallel in direction? 390. Demonstrate on the black-board the method, when these forces are not parallel, in straight levers, 391; and in bent levers, 392. State the universal law of the lever, 393. Explain its application to the hand-barrow. 394. Give examples of various levers and their mode of action, 395, 396. Explain the baker's cart, 397; and other vehicles, 398. Demonstrate the application of the law of the lever to the stability of objects, 399; to the coach-wheel, 400; and to moveable rocks, 401.

Explain *the lever of indefinite power or engine of oblique action*, 402.

Explain to what order of levers the fixed pulley belongs; what good purpose does it answer? 404. Explain the mechanical advantage of the moveable pulley, 405. Explain it by another method, 406; and by a third, 407. Explain the action of the system represented in Fig. 163, 408; and in the system of blocks, Fig. 164; and in the system of independent pulleys, Fig. 165.

Explain the uses of the wheel and axle, 411. Also, its nature and laws of equilibrium, 412. Wherein does it differ most from the lever and pulley? Name some other machines acting like it, 413. Explain the *differential* wheel and axle, 414. What is the most convenient mode of judging of the mechanical advantages of combined systems of wheels and axles? 415. Describe the two chief modes of connecting or *coupling* wheels, 416. What is said of coupling by bands, chains, and cords? 417. What, of coupling by cogs? What is an *arbour?* What, a *pinion?* What is said of judging the power of wheels by the number of cogs? 419. How do you calculate the power of systèms of wheels by the law of the lever? 420. How are wheels applied to the measurement of time? 421.

Explain the mode of determining the mechanical advantage gained by inclined planes, by the resolution of forces, 423. Explain an apparent exception to the general law of momentum in machinery, 424. Give the general rule for calculating the effects of inclined planes when the direction of power is parallel to the plane, and when that of the resistance is perpendicular to the base, 425. How do we proceed when the forces act in other directions? 426. Give examples of inclined planes and their action in nature and art, 427.

Explain the height, base and length of the helix of a screw, 428, 429. How is the power of their inclined plane estimated? 429. How are power and resistance usually applied to the screw? 430, 431. Explain the differential screw and its action, 432.

What is said of the action of the wedge? 433. What, of the mode of calculating its effect? 434.

ombined Machines, - - - - - - - - page 196

How is power transmitted to a distance by machinery? 435.

Explain how vibratory, may be converted into circular motion, 437.
v may perpendicular, be changed into horizontal vibratory mo-
How is alternate circular, changed to rectilinear motion in

certain ship's pumps? 438. How is continued circular, converted into alternate circular or rectilinear motion, and the reverse? Explain this by the steam-engine, 439, 440. Explain the use of fly-wheels in machinery, 443. What is said of the irregular action of combined machines? 444. What is said of the fly-wheel in grist-mills and in steamboats? 444, 445. Why is it unnecessary in locomotive engines? 446.

By what contrivance is the supply of motive power to machinery made to regulate itself? Explain the construction of the *governor*, 447. Explain its action 448.

CHAPTER III.—Phenomena of Fluids.—(P. 206.)

Define *physics*, 450; *dynamics*, 451; *statics*, 452; *mechanics*, 453; *hydrostatics*, 455; *hydraulics*, 456. What is said of *hydrodynamics*? (*note*,) 457. What property varies the application of dynamic forces to liquids? 457. Define *pneumatics*, *aero-dynamics*, and *aero-statics*, 458. What causes vary the application of dynamic laws to gases? 459. Are the subdivisions of dynamics natural divisions? Explain this question at length, 460. Do we know any limit to the expansibility of gases? Give astronomical proof that the earth's atmosphere is limited. What is said of gaseous bodies in the heavens? 461. What is said of the variable density of liquids and gases? 462.

CHAPTER IV.—Hydrostatics.

Have friction and cohesion any thing to do with the equilibrium of liquids? 464, 465, 466.

State and explain the law of the equality of liquid pressure in all directions, 467, 468, 469. State and explain the law that liquid pressure varies as the depth, 470, 471. Give an illustration from Fig. 182, 472, 473, 474. Another from Fig. 183, 475. Another from Fig. 184, 476, 477. What inference is drawn from liquid pressure on the bottoms of great lakes compared with that of narrow tubes? 478. How do you estimate the pressure on the sides of vessels? 479, 480. Which sustains most pressure, a flood-gate two feet long by one deep, or a gate two feet deep by one in length, when both touch the surface? and which, when both touch the bottom of a reservoir? Where do we find the point of mean pressure? 481. What is said of the canal of Panama? 483. What, of a bottle sunk at sea? 484. What, of suddenly salting meat? 485.

Explain the hydrostatic paradox, 486. Explain the pressure of columns of water in narrow tubes upon that contained in confined reservoirs, 487, 488. What is proved by these facts? 489. Describe the Bramah press, 491; and its action, 492, 493; and how to

estimate its power, 494; and some of its effects, 495. How does fluid pressure affect the level of the surface of water? 496.

Explain how water may support heavy metallic bodies, 498. Explain the law of support for floating bodies, 499. When a body lighter than water is completely immersed in water, by how much force will it endeavour to rise? How much weight does it lose? 500. If a body just as heavy as water is placed in water, how much weight does it lose? 501. If a body heavier than water be immersed, how much weight does it lose? By how much force does it sink? Give a general law for these facts, 502. Do the same principles apply to compressible fluids? 503. State the law of fluid support in its most general terms, 504.

How do you ascertain the relative weight of any body when compared with that of a given fluid? 505. Explain the practical use of this calculation, 506. What is *specific gravity?* 507, 508. What is its common standard? 509. Give the shortest possible definition of the term, 510.

What effect has speeific gravity on the arrangement of mechanical mixtures? 511. Define *medium.* In what media do we commonly test specific gravity? 512. Explain the experiment of making a cork sink in water, 513. Explain the *water-balloon,* 514; and the air-balloon, 515. When is man a water-balloon? 516. How is specific gravity ascertained by measurement? How, by the graduated bent tube, 518. How, by the weighing beam? 519. How, by Coates's steelyard? 520. How, in solids lighter than water? 521. How, in liquids by measure? 522. How, by the *hydrometer?* 524. Of what use is the hydrometer in testing mixed liquids? 525. How do you find the specific gravities of gases? 526.

Explain the construction of the *barometer,* 528. Explain the range of the barometer, and its cause, 529. What has it to do with storms? 530; and with our feelings? 531. What is there in the top part of the barometer tube? 532. Describe the *water-barometer,* 533.

Describe the *common pump,* 534; and its action, 535; and the extent of its usefulness.

Describe the *common forcing-pump,* and its action, 538.

Describe the common *air-pump,* 539; and its action, 540, 541.

Describe the structure and uses of *condensing-pumps,* 542.

What is said of double *forcing-pumps?* 543.

What is the *centre of buoyancy?* Where is it found? Why is it a variable point? 545, 546, 547. Explain why and how ships and boats recover their position when rocked by waves, 548, 549. Explain the consequences of bad loading in vessels, 551. What has the law of the lever to do with these questions? 552.

CHAPTER V.—Hydraulics.—(P. 249.)

How does water flow from a long horizontal pipe? How, when the pipe is turned up at its extremity? 554. What is said of friction in long, narrow tubes? 555. Describe the *water ram*, 556. What effect has the bending of tubes on the flow? 557. What law governs the emptying of vessels by gravity? 558, 559. What effect has a long straight tube beneath a vessel on the flow? 560. Describe the height of jets from short tubes, 561. What law is deduced from this? How are jets modified by aerial friction? 562. Describe the effects of emptying vessels by simple orifices in the bottom, 563.

Describe the effects of the reaction of jets in propelling boats, 564; in explosions of steam, 565; in Barker's mill, and in gas-pipes, 566.

Explain the effects of atmospheric pressure on the escape of fluids from simple orifices, 567. How does a short tube hasten the discharge? 568. Explain the action of the syphon, 569; and intermittent springs, 570; and a curious action of the hydrant, 571.

What law regulates the impact of solids and liquids? Give an illustration, 572. How does hydrostatic pressure increase the liquid resistance to a moving body? 573, 574. Is this also true of aerial resistance? Give illustrations from the action of projectiles, 575; and from the swell raised by vessels, 576. What has the form of a body to do with the resistance to its motion in a fluid? Give illustrations, 577, 578, 579.

Describe the formation of waves, 580. What gives to waves their progressive motion? Why do not waves interfere with each other? 582. When do two waves produce smoothness? 583, 584. Are waves ever rectilinear? 585. Describe the effect of a pier on sea-waves, 586. What is said of the reflection of waves? 587; of their height, 588; their bulk, 589; and their velocity? 590. What is said of the effects of general currents on their velocity? 592. What, of currents in channels? What is a *bore?* 593. What is said of the effect of wind on their form? 594. What, of very powerful winds? 595. Explain the effect of shoals on waves, the *under-tow*, and the *ground-swell*, 596. Also, on coasts, the *roller* and the *breaker*, 597.

What are tides, and their cause? 598, 599, 600. Why do the tides lag behind the moon? 601, 602. What effect has the sun? What are *spring* and *neap tides?* 603. In what way do tides resemble waves? 605.

CHAPTER VI.—Pneumatics.—(P. 271.)

What is the specific gravity of air at the surface of the sea? What is the relative density of steam to air at 212 degrees? What, the relative weight of oxygen; and what, of hydrogen? How much

has air been condensed? What effect has pressure on steam? 607. Does air permeate solids? 608. Describe and explain Hero's fountain. 609. Give illustrations of the weight of air. What is the weight of the atmosphere? 610. 611.

Give illustrations of the elastic force of air. 612. 613. 614. What effect has diminished pressure on the elastic force of air? How does elevation affect its density? 615. What is the law of density under pressure? 616. What are the relations between the elasticity, density, bulk, and pressure, of air? 617. What is the law of the increase of expansion and elasticity by heat? 618.

Give the rate of the decrease of atmospheric density in rising, according to the hypothesis of unlimited expansion. 619. 620. What is said of pumps and diving-bells? 621; and of sound and light at the height of 105 miles? 622. Prove the error of the hypothesis of unlimited expansion.

Explain how expansion produces atmospheric cold, 628. What is said of the absorption of heat by air? 629, 630. Explain the terrestrial absorption and radiation of the sun's heat, 631; and its effect on temperature at great heights, 632.

Explain the great cause of variation of climate, 633; and that of the seasons, 634. What is said of the limit of eternal frost in different latitudes? 635.

What is the great cause of winds and tropical calms? 636. What, their effect on climate? 637. Explain the causes and route of trade-winds, 639. Of gusts and storms, 639. Of monsoons and prevalent winds, 640. Of whirlwinds and waterspouts, 641. Of the rise of the barometer during some storms, 642. Of land and sea-breezes, 643.

What is said of evaporation *in vacuo*, and of a watery atmosphere? 644. What, of the expansive force of vapours at different temperatures? 645. How does vapour permeate air? 646. State M. Dalton's discovery, 647. Explain the influence of temperature on the boiling-point, 648. What is said of freezing by evaporation, and the evaporation from ice? 649.

What effect would the absence of wind produce on the moisture of the air, on clouds, rain, &c.? 650. Describe the effect of an upward current in such an atmosphere, 651; that of a downward current, 652; and that of equatorial and polar currents, 653. What is the actual condition of the atmosphere with regard to the distribution of moisture? 654. What effect has the exhaustion of air by the air-pump on aerial moisture? 655.

Explain the theory of dew, and the dew-point, 656, 657.

Explain the formation of ordinary summer clouds, 658, 659; that of hail and snow, 660; the influence of sea-fights and fires on storms,

661; the formation of cloudy strata at various elevations, 662; and the cause of the rainy season, 663.

What is a *hygrometer?* Describe that of M. de Saussure, 664.

CHAPTER VII.—Acoustics; or the Science of Sound.—(P. 291.)

Explain the nature of *a pulse of sound,* 665; and the application of dynamic laws to its direction, 666. Describe the structure of the ear, 667. Of what nature are the causes of sonorous pulses? Give examples, 668. How do they cause pulses in bodies on which they impinge? Give illustrations, 669. What happens to sound in rare media, and *in vacuo?* 670. Is the ear necessary to hearing? 671. What relation has sound to distance? 672.

Explain the reflection of sound, 673. Prove that the pulses of sound are regulated by the same laws that govern waves. How long does the impression of sound last? Illustrate this. What causes the difference between noise and a musical note? 674. Explain the nature of echo, and the rolling of thunder, 675. Explain the nature of *whispering galleries,* 677, 678. Give examples, 679. Explain the reflection of sound in hollow spheres, 680; and along tubes, 681. Give instances from juggling-tricks, 682. Explain the *speaking-trumpet,* 683; and the *ear-trumpet,* 684.

Explain the cause and production of musical tone, 686. Explain the relation of the beat of the pendulum to the vibrations of strings, 688. How many vibrations per second are required to arouse the sense of hearing? How many can be separately recognised by the ear and eye? How many produce a clear musical note? 689. Explain the terms *pitch, low, grave, bass, high, acute,* in music, 690. Repeat the laws of relation between the length, tension and weight of strings, and the number of their vibrations, 691, 692, 693, 694, 695.

Explain the nature of musical *interval,* the *fundamental tone* and its *octaves,* 696; that of *concrete* and *discrete* sounds, *cadence* in speech, *song* and *recitative,* 697.

Explain the nature of the division of the octave into *notes.* Name the notes, and the relative lengths of string and number of vibrations producing them. What is the entire range of human hearing? What is said of that of other animals? 698.

Explain the terms *unison, concord, discord,* 699; and musical *chord,* 700. Are the intervals of musical notes positive or relative? 701. Explain the terms *gamut, diatonic scale,* and *chromatic scale,* and *key-note,* 702. Explain the natural succession of *major tones, minor tones,* and *semitones* in the octave; also the nature of *sharps, flats* and *accordance* in music, 703. Explain the nature of the *key* in music, 704.

Explain *the spontaneous division* of vibrating strings, the formation of *knots,* and the *grave harmonic,* 705. Prove that the divisions of

musical notes are founded in nature, 70[illegible], 70[illegible]. Explain the nature of *melody*, 70[illegible] and *harmony*, 709. How are instruments attuned? 71[illegible]

Explain the longitudinal vibrations of rods and the air in tubes, open at one or at both extremities, 7[illegible]. What is the use of keys and finger-holes in wind-instruments? 7[illegible]. What is said of *spontaneous division* in wind-instruments? 7[illegible]. What of the visible vibrations of bells, and those painted by waves in a goblet? 615, 616.

What is said of *sympathetic sounds*? 7[illegible]; *the sounding-board*? 718; and the Æolian harp? 72[illegible].

What is said of the transmission of sound through different media, and from one to another? 72[illegible], 72[illegible], 72[illegible], 724.

How rapidly does sound travel? How do temperature and density affect its rate? 72[illegible]. How can we judge distance by sound? 726. What is said of its rate through various media? 727. What, of the distance at which sounds are heard? 728. Give examples of the conducting power of solids, 72[illegible], and of the effect of temperature on music, 730. What is said of the organs of voice? 731.

CHAPTER VIII.—OPTICS.—(P. 316.)

What is a ray, and what a *beam* or *pencil* of light? 733. What is meant by a *pulse* of light? 735. Which hypothesis has been adopted, and why? 735. State the sources of light, 736.

What is the velocity of light? How was it calculated? 737.

Explain and illustrate the *refraction* of light, 738, 739, 740. Explain the meaning of parallax, 741.

What is *reflection* of light? 742.

Explain the *reflection* of light, and its law. Give examples, 743.

Explain the phenomena of *penumbra*, 744, 745. Explain the nature of *partial*, *total*, and *annular eclipses*, and *transits*.

Explain *transparency*, *translucency*, *opacity*, 747, 748. Are these properties ever perfect? What is meant by *absorption* of light? Give examples of the transmission of light by bodies called opaque, 749, 751; and its absorption by transparent media, 750, 751.

Do colours belong to bodies or to light? 752. How are they explained? 753. What always happens to light when it reaches ponderable bodies? 754. Explain the formation of images by light passing through small openings in dark chambers, 655, 756, 757.

Catoptrics, or the Reflection of Light, - - - - - page 327

Demonstrate the angles of incidence and reflection on plane mirrors, 761; on concave spherical mirrors, 762; on convex spherical mirrors, 773. Explain the effect of irregular mirrors upon a ray, 764; and the effect of perpendicular incidence, 765.

Explain the course, after reflection, of parallel incident rays on plane mirrors, 766. Also, of converging rays. Also, of the formation of

virtual images by such mirrors, 767. Give additional particulars, 768; and still others, 769. Explain the properties of virtual images, 770. What is the course of diverging rays? 771. Explain how the eye sees images, 772, 773.

Explain reflection of parallel incident rays from convex spherical mirrors, 774. What is said of the principal focus, and of true foci? 775.

What is said of the course, after reflection, of rays incident on convex spherical mirrors, and of their foci? 776. Demonstrate the formation of *virtual images* by such mirrors, 777, 778. What is said of the effects of distance on such images? 779.

Explain the effects of reflection from cylindrical convex mirrors, 780, 781.

Explain the effects of concave spherical mirrors on parallel incident rays, and their *actual foci*, 782. Also, on divergent rays and their *conjugate foci*, both *real* and *virtual*, 783. Explain the formation of *real images* by such mirrors, 784.

What is said of reflection from transparent surfaces? 785.

Dioptrics, or the Refraction of Light, - - - - page 396

Explain the probable cause of refraction, 787. What is the effect of a transparent medium with parallel faces on rays passing through both faces? 788. Does refractive power depend on density? 789. Demonstrate the general law of refraction, 790, 791. What happens to rays having perpendicular incidence? What is *the index of refraction*? 792. How does it vary? What is its use? 793. What happens when rays leave a denser for a rarer medium? 794.

Explain the nature and cause of *total reflection*, 795, 796, 797.

Demonstrate the mode of finding the course of a ray, after refraction, by curved surfaces, by means of the index of refraction, 798.

What is a lens? Describe the varieties of lenses, 799.

Describe the effect of spherical lenses upon incident rays and their foci, 800. What effect has the index of refraction upon the focus? 801.

Describe the formation of the double convex lens, 802. How does it differ from the spherical? Where is its focus for *direct* parallel rays? Where, for oblique ones? 803. What is said of the distortion of oblique rays? To about what is the principal focal distance of a glass double convex lens equal? 805. Why do such lenses form burning-glasses? 806. What are their effects on converging and diverging rays and their foci? 807.

How do plano-convex differ from double-convex lenses? 808.

How do double-concave lenses compare with double-convex ones? 809.

Explain the formation of images by lenses, 810. State the properties of such images, 811. How are their size and brightness influenced by the form of the lens? 812. How are they rendered visible in the air? 813.

Explain the magnifying power of lenses, 814. What would be the structure of the simplest possible telescopes? 815.

Explain the structure of the human eye, and the mode in which it forms inverted images. What optical instrument most resembles it? 817. Why must it adapt itself to the distance of objects? What effects have age and the form of the cornea on vision? How are these effects partially remedied by art? 818. Why do we see indistinctly at less than six inches distance? 819. How can we remove this difficulty? 820.

What constitutes a *simple microscope?* what, a *compound microscope?* what, an astronomical *refracting telescope?* what, a *terrestrial telescope* or *spy-glass?* what, a *reflecting telescope?* and what, a *reflecting microscope?* Describe the astronomical refracting telescope, 821. Describe the spy-glass, 822, 823. Describe Newton's reflecting telescope, 824.

Demonstrate the nature of *spherical aberration*, 825, 826. How is this partly remedied by art? 827; and wholly by nature? 828.

Chromatics, or the decomposition of light, - - - - page 351

Describe the solar spectrum, 830. Explain it on the hypothesis of radiation, 832. What is said of the illuminating power of the separate rays, and of their limits? What was the Newtonian doctrine of the coloured rays? What was Brewster's discovery? What happens whenever light is refracted? 833. Why do we so seldom see iridescent colours in refracted light? 834.

What is said of invisible rays? 835.

What, on the nature and causes of *chromatic aberration?* 836, 837. What are the structure and uses of achromatic lenses? 837.

Describe the nature and causes of primary and secondary rainbows, 838, 839, 840, 841.

Double refraction and polarization, - - - - - page 355

What classes of bodies possess single, and what classes have *double refraction?* 842, 843. Demonstrate the double refraction of Iceland spar, 844, 845. Explain what is meant by the *polarization of light*, 846.

CHAPTER IX.—Electricity.—(P. 357.)

Define the terms *electric* and *non-electric*, 847, 848. What are the properties of the agent producing such effects, and what is it called? What was Franklin's discovery? 849. What is meant by *conductors* and *non-conductors* of *electricity?* 850. What are *electroscopes* and *electrometers?* 851. Describe the *pith-ball electrometer*, 852, 853.

What is meant by *opposite states of electricity?* Describe the *gold-leaf* electrometer, 854. Describe its uses, 855. State the electrical hypothesis of Franklin. State the hypothesis of double fluid. Which is adopted in our descriptions? From which have we taken our terms? 857. How does electricity diffuse itself over conductors? 858, 859. What influence has the form of the conductor on the in-

tensity of the fluid in different places? 860. What effect has it on the spark and the *striking distance?* Explain the action of the lightning-rod, 861. What electric effect follows the contact of dissimilar substances? 862.

What effect follows the approach of a charged conductor towards another conductor, insulated and in the natural state? 863. Illustrate this by a series of experiments, 866 to 870. What appears to be proved by these experiments? 871. Why do two bodies, one of which is in the natural state and the other charged, attract each other? 872. What term is applied to this mode of electrizing bodies by the proximity of charged bodies? Show the danger following the electrized condition of the earth in thunder-storms, 873. Explain the experiment with two discs, charged with opposite electricities, 874. What is said of the *discharge* of these discs? 876. What is the effect of substituting a solid electric for the air in this experiment? 877. What happens when only one of the discs is charged? 878. What effect has atmospheric moisture on electric experiments? 879. How does air carry off electricity? 880.

Describe Nairne's electrical machine, 881, 882. Describe its action under various circumstances, 883 to 886. What effect follows substituting a cylinder of resin for that of glass? 887. Explain the doctrine of the double current, 888.

At what rate does electricity travel along conductors or through non-conductors? 889. What route does it often take along crooked or narrow conductors? 890. What mechanical effect does lightning produce on air? 891.

Explain the *Leyden vial*, 892, 893; and the *electric battery*, 894. How are they discharged? 895. What effects have they on the human body?

What is said of electricity eliminated by chemical changes and animal organization? 897.

CHAPTER X.—GALVANISM.—(P. 371.)

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How may this circle be extended? How does it affect taste? 903. How may the circle be completed by a moistened thread? 904.

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CHAPTER XI.—MAGNETISM.—(P. 375.)

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What substances are now known to possess magnetism? 915.

What was Professor Oersted's discovery in relation to the electric nature of magnetism? 916. What has Mr. Faraday accomplished for the science?

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Describe the mode of magnetizing steel by the galvanic current. Also, the mode of making permanent magnets of steel by similar means, and that of reversing the poles, 920.

Describe the mode of making temporary magnets of soft iron by the galvanic current, 921. How may magnetism be made use of in driving machinery by circular motion? 922.

Describe the mode of creating magnetism at any required distance, for the purpose of acting on machinery, 923, 924, 925.

Describe and explain the *electro-magnetic alarm-bell*, 926.

Describe and explain the electro-magnetic telegraph, 927, 928, 929.

THE END.